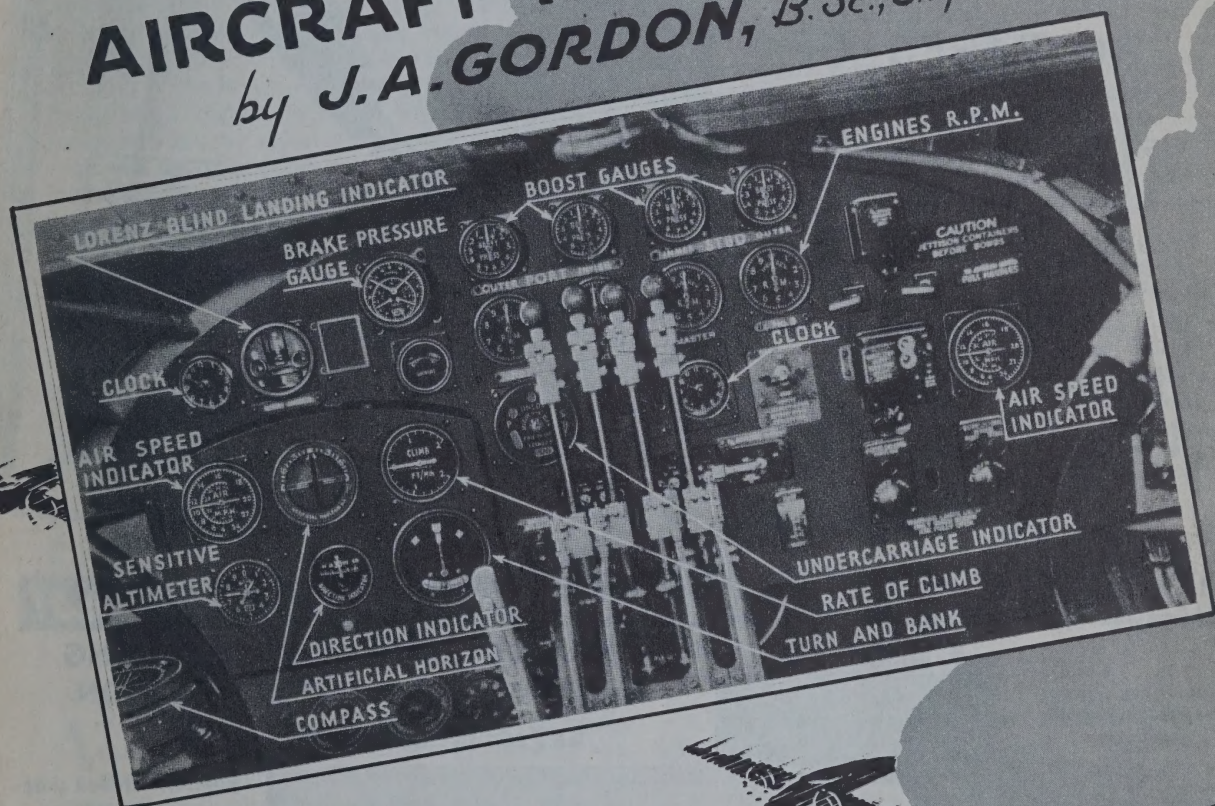


CONSTRUCTION= MAINTENANCE and REPAIRING of AIRCRAFT INSTRUMENTS by J.A. GORDON, B.Sc., Eng.



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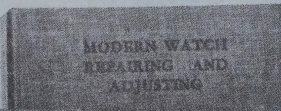
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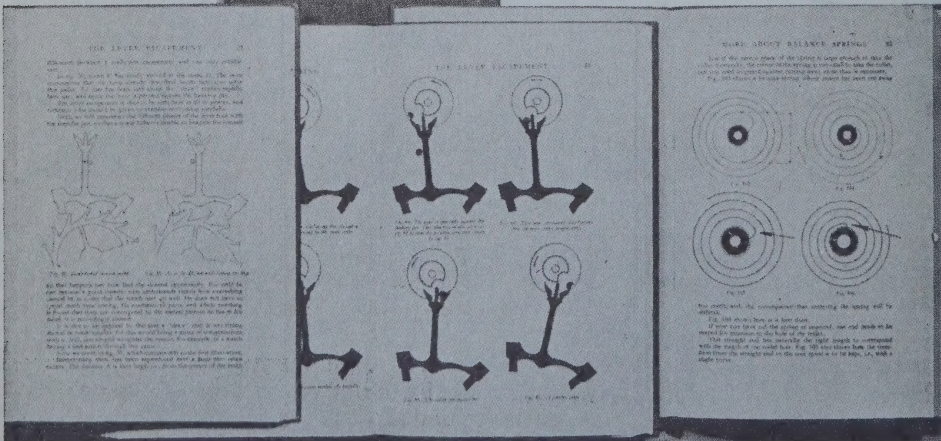
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AIRCRAFT INSTRUMENTS

Their Construction, Maintenance and Repair, by J. A. GORDON, B.Sc., Eng.

INTRODUCTION

IN recent years, particularly since the mad race for air supremacy began, aircraft instruments have assumed an importance never anticipated in the early days of aeronautics. Flight training was then mostly directed to teaching a pupil to develop the "feel" of the machine, and to understand its behaviour by the use of his ears and eyes. Instruments were few, unreliable, and in most cases a natural distrust of them existed. The impression that instruments are unreliable persists in some circles, even to this day. This is not so, as the accuracy of the R.A.F., in locating their targets when flying blind, that is, flying by means of the instruments and not by visual observation, would prove.

British aircraft instruments rank among the finest in the world, and considering the amazing degree of accuracy they have attained, are remarkably robust.

These articles are not intended to be a general treatise on aircraft instruments, but rather in the nature of a correspondence course for watch-makers desirous of entering the industry as aircraft instrument mechanics for the duration of the war.

It may be noted that some of the instruments included in these articles are obsolescent, but these, as well as other types, have been included because they illustrate the general principle involved.

It is my intention to follow as closely as possible the syllabus supplied by the Air Ministry for the purpose of training at Ministry of Labour Training Establishments, but, certain omissions will have to

be made. For obvious reasons, I shall be unable to write for publication an article on the Bomb Sight; also, by virtue of my readers being watch-makers, the first part of the syllabus can be ignored. It reads:

"Benches, vice and clamps, riveting stakes, screwdrivers, pegwood and pith, tweezers and pliers, removing rusted screws, making taper pins, blueing or colouring steel, removal of pointers, tightening loose pointer-collets, making and fitting a new pointer, fitting glasses to instrument cases, repainting cases and dials, closing worn pivot holes, bushing worn pivot holes, replacing a broken pivot, use of Jacot tool, use of pivot and burnishing files, making and hardening springs, punching a hole in a spring, and about 500 words devoted to hairsprings."

Compass repair is a specialised branch of the industry, and unless the articles take less time than I expect, I shall not deal with compass maintenance and repair. If, however, there is any particular subject upon which a reader desires information, I shall be only too pleased to supply it; all questions and queries on the monthly articles will be promptly answered. Further, I have a knowledge of conditions and rates of pay operative in most of the firms dealing with these instruments and shall be pleased to advise readers in the choice of a situation or other matters.

PROBLEMS OF DESIGN

AFTER many years at the watch bench the reader may be inclined to view aircraft instruments in a horological light, whilst they are similar in many ways, certain special conditions which may be regarded as essential features of design must be satisfied to ensure correct functioning.

1. To withstand vibration and taxi-ing, instruments must be more robust than stationary mechanisms.

2. Size and weight are extremely important, instruments must be compact, in order to occupy a minimum amount of space. Every ounce of weight added to an aircraft adds approximately six shillings to the cost.

3. Moving parts must be balanced wherever possible to reduce error when the aircraft tilts, as well as to avoid inertia effects when increasing or decreasing speed.

4. The readings of the instrument must not be affected by changes of temperature. (This will be dealt with in a later article.)

5. The readings of the instrument must be correct, irrespective of the position the aircraft assumes.

6. The dial must be marked in such a manner to permit of no uncertainty of the reading.

7. Suitable damping of the pointer must be provided to enable it to take up its position quickly and give a steady reading.

8. The natural vibration of the moving parts must bear no relation to the natural frequency of vibration of the engine or the pointer would oscillate violently, and it would be impossible to obtain a steady reading.

9. Owing to the frequent need for the overhaul of aircraft instruments they must be easy to remove and re-install.

As in the case of engines and airframes, certain conditions are imposed by the Air Ministry in the manufacture, calibration and performance of all instruments, and as a rule a certificate from some approved testing authority must be produced before installation. For further conditions and information I would refer the reader to the *Airworthiness Handbook of Civil Aircraft*, Vol. I, leaflets A8, A9 and E1.

CLASSIFICATION OF INSTRUMENTS

The principal instruments used in aircraft may be classified as follow :

A.—Engine Performance Instruments.

1. Engine speed indicator.
2. Oil pressure gauge.

3. Fuel-pressure gauge.
4. Oil temperature thermometer.
5. Radiator temperature thermometer.
6. Boost gauge.

B.—Aircraft Performance Instruments.

7. The altimeter or height indicator.
8. The air-speed indicator.
9. Inclometers—cross levels—fore and aft levels.

C.—Navigational Instruments.

10. The compass.
11. The watch.
12. The turn indicator.
13. The directional gyro.
14. The artificial horizon.
15. The rate-of-climb indicator.

THE LINK AND LEVER PRINCIPLE

PRACTICALLY all differential-pressure instruments of the mechanically-operated dial and pointer type are dependent for their calibration upon what is known as the link and lever principle, and before anyone contemplates any repair or calibration to aircraft instruments, it is very necessary thoroughly to understand this principle. Imagine a simple double-lever pivoted centrally, as shown at Fig. 1; any movement at (a) will be transmitted directly at (b). If the fulcrum be moved to a distance two-thirds from one end, as shown in Fig. 2, then the movement at (a) will produce a geared travel in the ratio of three to one at (b). Had the motion been applied at (b), then the travel at (a) would be $b/3$.

Applying this principle to the pressure gauge illustrated in Fig. 3, it will be seen that the toothed quadrant or sector is the pivoted lever, and that the distance between the pivot and the link-bearing can be varied, the nearer the two are together the more revolutions of the pinion will be obtained for a given movement of the link. In this case adjustment is simple, it is only necessary to slacken the screw (a) and slide the link to or from the quadrant to alter the speed of the pointer. In the cheaper class of instrument, adjustment is effected by bending the quadrant loop with a small pair of pliers. (see Fig. 5, Fuel Pressure Gauge.)

It will be seen that the aforementioned principle will correct all regular pointer errors, that is, fast or slow, but an irregular error will be met with in this class of instrument. The pointer will travel over the first few calibrations on the dial correctly, but will then begin to lose, the farther round the scale the pointer goes the greater will be the loss per calibration. This is explained as follows: the radius of the arc shown in Fig 4 represents the distance between the connecting-pin hole and the pivot on the quadrant, the vertical line the link through which the motion is transmitted.

If link and lever at rest make an angle of ninety degrees when the lever starts moving, it will move through an equal series of angles towards the finish of its motion and the angles will have got longer, making the lever have to travel a greater distance

Double levers pivoted centrally will give equal travel at the ends.

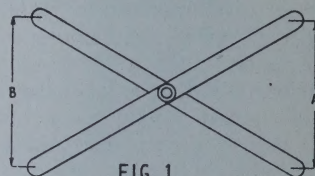


FIG. 1.

Placing the fulcrum away from the centre will give a geared travel, depending for ratio on the position of the fulcrum

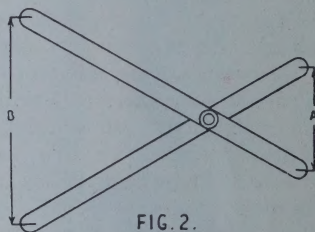


FIG. 2.

than previously to move the link the same distance. The link and lever should, therefore, form an angle of ninety degrees at the centre of their motion and not at the beginning or end.

A few minutes study of the sketch Fig. 4, and comparison with the pressure gauge shown in Fig. 3, should make this quite clear.

Adjustment is quite easy, as the link is usually cranked and can therefore be lengthened or shortened at will.

It must be borne in mind that the movements of these instruments are greatly magnified by gearing, so that relatively small adjustments are needed to make the necessary alterations to the pointer.

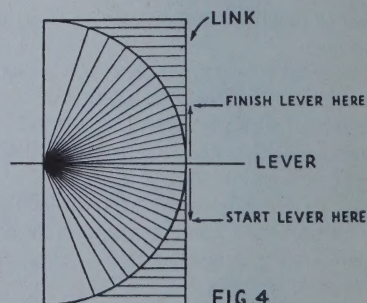


Diagram illustrating link and lever principle of pressure gauge.

FIG. 4.

Fuel-Pressure Gauges

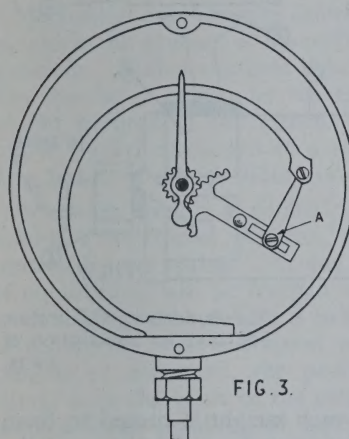
General.

1. The fuel-pressure gauge is used in aircraft to indicate the pressure in the fuel-supply system.
2. The principle most commonly employed for the measurement of fluid pressure is that whereby the pressure is caused to deflect some elastic member, the deflection of which is suitably magnified and shown upon a dial. For the measurement of pressures of one pound per square inch and upwards the Bourdon tube principle is found convenient.
3. The Bourdon tube consists of a brass or copper tube of oval section, which is bent into a nearly

the case of a hose pipe when a fairly high pressure of water is turned on quickly. The free end accordingly moves through a small distance, which is proportional to the excess of pressure in the tube above the atmospheric pressure to which its outer surface is exposed.

Construction.

Fig. 3 shows the Bourdon tube and link-and-lever mechanism of a fuel-pressure gauge. The free end of the Bourdon tube is linked to a toothed quadrant engaging with a pinion on the pointer spindle. The size of the pinion is chosen so that the movement of the link is suitably magnified. A hair-spring is



Figs. 3 & 5. A simple pressure gauge action showing application of link and lever principal with the Bourdon tube.

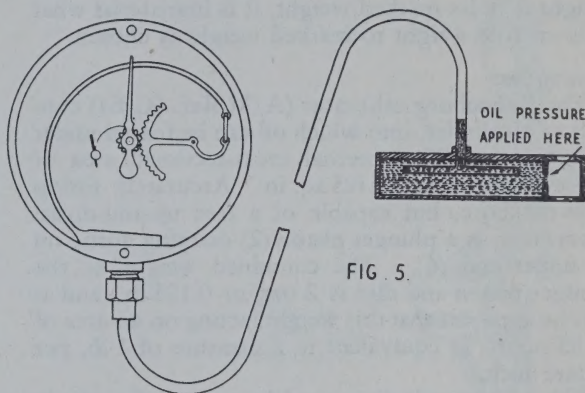


FIG. 5.

circular form. One end is closed and free to move, the other held fixed and open to the liquid or vapour. The pressure inside the tube tends to make the oval section circular and thus straighten the tube as in

fitted to the pointer spindle to take up any backlash, and a stop is fitted, limiting the movement of the Bourdon tube, to prevent damage to the instrument due to the imposition of an overload.

General.

Oil Pressure Gauges

1. The oil-pressure gauge illustrated in Fig. 5 is for the purpose of indicating at a distance the pressure in an engine lubricating system, the oil itself being entirely isolated from the distant indicator.
2. The instrument is of the type which employs an indicator of the Bourdon tube type, a capillary tube, and a flexible nickel-silver capsule. The Bourdon tube, capillary and capsule, are completely filled with ethyl ether, or other approved liquid, and are so mounted that the pressure under measurement is applied to the flexible capsule and thereby transmitted through the capillary to the Bourdon tube. The principle is shown diagrammatically in Fig. 5.

Description.

3. The mark I.X.C. transmitting type oil-pressure gauge is shown in Fig. 6. It consists of three parts, the indicator (1), the capillary (2), and the capsule fitting (3). The indicator is of the standard type with a Bourdon mechanism.

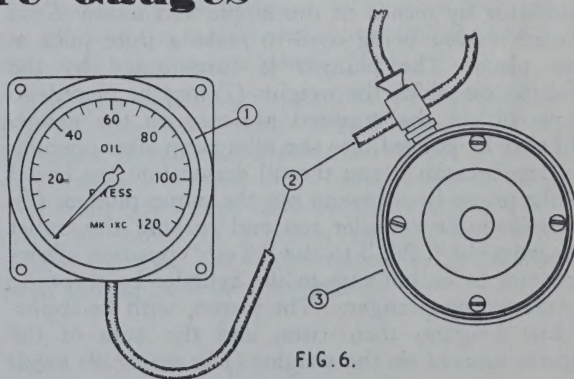


FIG. 6.

AIR PRESSURE GAUGES

Air-pressure gauges are instruments which show on a dial the pressure obtaining at the point of a compressed-air system to which they are connected. They are applicable to any system using compressed air, such as engine starters and automatic controls. The gauges make use of the Bourdon tube principle as in the oil-pressure gauge indicator.

Pressure Gauge Calibrator

General.

The calibrator used for the purpose of checking the accuracy of the open-ended Bourdon type of indicator is of the dead weight oil-operated pattern, made by the well-known firm of Budenburg Gauges, Ltd., of Altringham, Cheshire. The operation and principle is very simple. Referring to Fig. 7, it will be seen that the oil under pressure supports a weight and at the same time gives a reading on the gauge to be tested. To avoid unnecessary weight and bulk, each weight is a certain fraction of its marked weight. Providing that the cross-sectional area of the supporting surface of the oil is the same fraction of a square inch as the actual weight is of its marked weight, it is immaterial what ratio of true weight to marked weight is chosen.

Description.

The Budenburg calibrator (A/M Ref. 6C/84) consists of a cylinder, into which oil can be forced under pressure (1). The internal cross-sectional area of the cylinder being 0.125 sq. in. Accurately fitting into the bore, but capable of a free up-and-down movement, is a plunger piston (2) carrying a disc on its upper end (6). The combined weight of the plunger piston and disc is 2 oz., or 0.125 lb., and it will be apparent that this weight, acting on an area of 0.125 sq. in., is equivalent to a pressure of 1 lb. per square inch.

The calibrator is connected by means of a nipple and union to the gauge to be tested, and arranged in such a manner that the dial can be conveniently read.

Situated on one side of the cylinder is the oil-filling cup (4), underneath which is a tap which has two positions, marked "Test" or "Fill."

The gauge under test is seen connected to the calibrator by means of the nipple and union (5), a leather washer being used to make a tight joint at this place. The plunger is surmounted by the disc (6), on which the weights (7) may be placed, so as to obtain the required pressure on the gauge. Oil may be poured into the filling cup after opening the tap beneath it and the oil drawn into the barrel of the pump by screwing out the pump plunger (8).

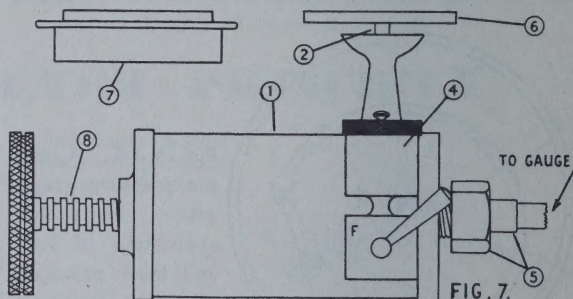
Closing the oil-filler tap and turning the outlet tap from the "Fill" to the "Test" position allows pressure to be built up in the cylinder by screwing up the pump plunger. The piston, with its appropriate weights, then rises, and the sum of the figures marked on the weights (*plus one for the weight*

of the disc itself) indicates the pressure applied to the gauge under test.

Equipment.

The weights provided with the calibrator usually are fourteen in number, and their markings are given below :

9	weights marked	20 lb.	} equivalent pressure.
1	"	10 lb.	
1	"	4 lb.	
2	"	2 lb.	
1	"	1 lb.	



The Budenburg Calibrator.
See text for description of parts.

The under-face of each weight is turned to form a shallow well, so that it retains its position on the disc, and the upper face of each weight is turned to form a raised portion, so that it engages with the under-face of the next weight to be added. The tendency for the weights to slip when they are piled on the disc is thus avoided.

Operation.

Gauges should be tested at from 5 to 10 points equidistant over the scale; e.g., a gauge of range 0 to 20 might be tested at 0, 5, 10, 15, 20, while a gauge of range of 0 to 100 might be tested at 0, 20, 40, 60, etc.

Starting at zero, readings should be taken at successive points by adding weights as necessary until the maximum is reached. The readings should then be checked *down* the scale, as the weights are progressively removed until the zero is reached again. The total test should take from twenty to thirty minutes, depending on the size of the gauge, as a quicker rate might introduce errors due to lag.

MECHANICAL ENGINE SPEED INDICATOR

THE engine-speed indicator is used on aeroplanes to indicate the rate of revolution of the crankshaft of the engine to which it is connected. This instrument is sometimes referred to as a tachometer or revolution indicator. The engine-speed indicator should not be confused with the revolution counter, which can only be used in conjunction with a stop-watch for counting up the number of revolutions in a given time of any shaft to which it is connected.

PRINCIPLE

Mechanical engine-speed indicators are of the type in which the pointer is controlled by a centrifugal governor. A diagrammatic sketch is given in Fig. 1. The spindle is driven by the engine and carries a weight pivoted in the centre. In the sketch one end is shown connected to a spring and the other by a link to a sleeve sliding on the spindle.

When the spindle is rotated, the weight tends to assume a horizontal position, this tendency being resisted by the spring. At any given speed a state of equilibrium will be reached when the centrifugal force acting on the weight is balanced by the tension of the spring. As the speed of the spindle is increased or decreased, the position of the weight alters, since the value of the centrifugal force alters, until a fresh position of equilibrium is reached. Movement of the weight is communicated to the sliding sleeve by the link, and this sleeve in turn actuates the pointer of the indicator through suitable multiplying mechanism. In a well-designed instrument there is a definite position of the weight, and hence the pointer, for every speed of rotation of the spindle.

Although the principles of operation remain the same, all Royal Air Force mechanical indicators being of the centrifugal type, the governor mechanisms of different instruments may vary, different makers adopting different designs. These variations only affect the governor and actuating mechanism, since the range, numbering of divisions, dimensions, materials, and other particulars are laid down in the Air Ministry specification for the particular instrument.

A largely used mechanical indicator is made by

North and Sons, Watford. The dial is marked in hundreds of revolutions per minute. An aperture is provided in the dial of the instrument, through which some part of the mechanism can be viewed, as a means of determining whether the engine is running when its speed is less than the lowest indicated on the dial. The indicator is usually mounted on the instrument board and is driven from the engine by means of a flexible drive. The speed of this drive has been standardised at one quarter of the crankshaft speed, and the shaft to

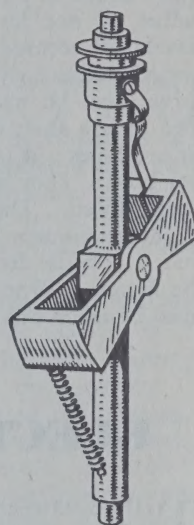


Fig. 1.
Principle of
Engine Speed
Indicator.

which the flexible drive is connected at the engine end is geared to the crankshaft to run at this speed. The indicators are designed to indicate four times the speed of the flexible shaft connected to them and thus indicate true crankshaft speed.

The construction of the flexible drive is shown in Fig. 2. The flexible shaft is built up of steel wire in layers lapped in alternate directions (1). The outer casing is of brass with a packing of asbestos (2). The drive is anchored to the engine and to the indicator by means of a union nut (3), and a slip washer (4) over the shaft connector (5) retains it from sliding back into the casing.

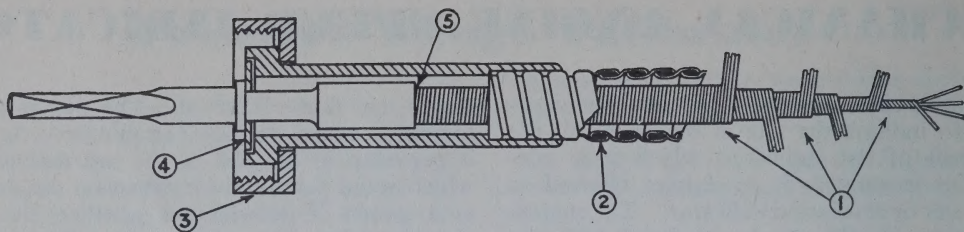


Fig. 2.
Details of flexible drive for engine speed indicators

INSTALLATION OF FLEXIBLE DRIVE

The flexible drive should be placed in the shortest convenient route possible, and should have as few sharp bends as possible. The bends should have a radius of not less than nine inches. The drive should be secured throughout its length and supported particularly well at bends. No part of the drive must be within eleven inches of a compass. The square shaft ends should be an easy fit in the square holes; it is most important that they should not bind. They should be greased before they are finally fitted. The shaft should first be connected to the instrument and a check should then be made that it is quite free by turning the other end with the fingers. When the other end is connected care must be taken that the shaft connector does not bind

when the union nut is tightened.

MAINTENANCE

The flexible drive should be periodically inspected and greased. The shaft should be withdrawn from the casing after carefully removing one of the slip washers, and should be examined thoroughly. No strand should be broken or badly worn and the end connectors should be secure. The flexible shaft and connectors should be thoroughly greased with Air Ministry anti-freezing grease. After the shaft is replaced in the casing the slip washer should be replaced and carefully flattened out.

The gear boxes should occasionally be examined internally and packed with grease.

ELECTRICAL ENGINE SPEED INDICATOR

THE electro-engine speed indicator is used to indicate the speed of the rotation of the engine crankshaft on multi-engined aeroplanes, where the engines are situated at a distance from the instrument board, rendering the use of the mechanical types inconvenient. The use of this type of instrument also enables several indicator movements to be used side by side in one instrument case.

These instruments consist of two units, the generator and the indicator. The generator is a d.c. dynamo of the permanent-magnet type, which generates a voltage depending upon the speed of rotation of the engine crankshaft, from which it is driven. This voltage is measured by the indicator, which is really a voltmeter of the moving-coil type, having a pointer moving over a scale graded in revolutions per minute. The generator and indicator can be fixed at a considerable distance from each other, inter-connection being made by twin flexible cable.

The generator is driven from the engine by means of a short, flexible shaft, the drive being transmitted through a gear box incorporated in the generator. The flexible shaft is normally driven at one quarter of the engine speed and the ratio of the step-up gearing in the generator gear box is normally four to one. Thus the generator runs at engine speed.

Each generator is designed so that it may be used

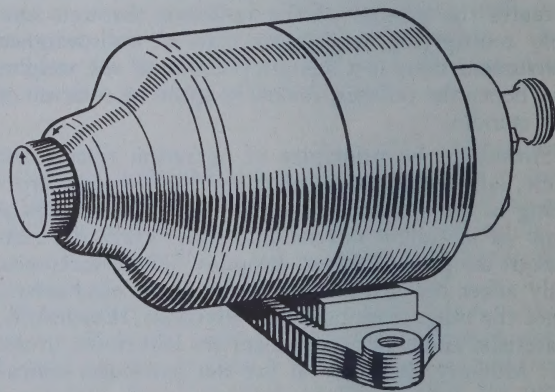


Fig. 3. Generator.

to operate either one or two indicators. When only one indicator is in use a shunt resistance is connected across the generator, Fig. 3. When two indicators are in use this resistance is cut out by means of a milled knob on the end of the generator (see Fig. 3).

The indicator movement is in effect a moving-coil voltmeter having a pointer moving over an edgewise scale. Two or three movements may be mounted side by side. The indicator movement is shielded to minimise interference with the compass and to prevent external magnetic influences from affecting the calibration.

OIL TEMPERATURE THERMOMETER

THE oil temperature thermometer is provided to indicate to the pilot the temperature of the engine lubricating oil. Knowledge of this temperature is of particular importance in the case of air-cooled engines, as this instrument normally provides the only indication of the temperature of the engine.

As the working range is in the neighbourhood of twenty degrees C. to seventy degrees C.; this precludes the use of an ordinary vapour-pressure type, as used for the radiator, owing to the fact that the law connecting vapour pressure of ethyl-ether with temperature is not suitable to the measurement of temperatures below forty degrees C. The mercury expansion type, which is fundamentally a development of the ordinary mercury in glass thermometer, is, therefore, used for measuring oil temperature. Instead, however, of the expansion of the mercury being measured as a length in a glass capillary, the mercury in this instance, completely fills a bulb connected by a steel capillary to a bourdon type of pressure gauge. The expansion of the mercury in the bulb consequent upon an increase in temperature is transmitted as a flow in the capillary and manifested as a dilation of the bourdon tube, to which is connected the pointer.

The bourdon tube in this case is not a semi-circle, but is coiled into a double spiral and itself acts as a spring, thus avoiding backlash (Fig. 4). The effect of expansion of mercury in the system is to reduce the number of coils in the bourdon tube, thus rotating the spindle. A bi-metallic spiral, consisting of a strip of brass and a strip of Invar steel joined so that the former is on the outside, forms the innermost coil of the bourdon. One end of this compensation strip is attached to the free end of

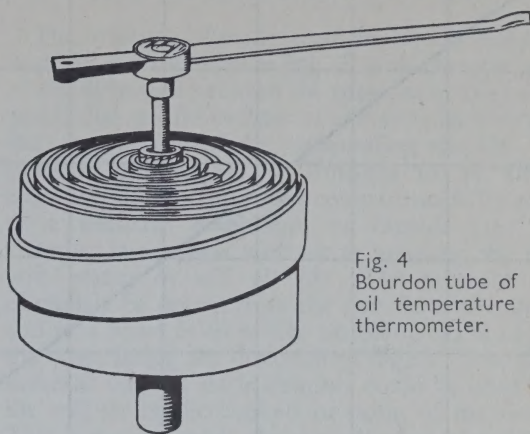


Fig. 4
Bourdon tube of
oil temperature
thermometer.

the bourdon tube; the other is wrapped round the centrally-mounted pointer spindle. In this way the instrument will not be affected by variations of air temperature as the bi-metallic spiral will wind the bourdon for an increase in temperature, and unwind it for a decrease, in opposition to the motions of the bourdon tube under changes of oil temperature.

CHECK ON ACCURACY

The accuracy of this instrument may be checked by a master thermometer, in the same manner as recommended for the radiator thermometer. No repair can be made to any part of the instrument, and it should, if faulty, be returned to the makers. In this class of instrument it should be noted that the pointer is shellaced on to the spindle—not pressed on. It will be realised that should a pointer be sprung off with pliers or pointer-remover in the usual manner, it would result in the coils of the bourdon tube being telescoped.

RADIATOR THERMOMETER

THE radiator thermometer is fitted to water-cooled engines to indicate the temperature of the cooling water, and thus to give warning of over-heating or loss of water. The complete instrument is of familiar type. The thermometer bulb is fitted in the water-jacket of the engine at its hottest point, usually the uptake pipe or the radiator. The indicator is fitted on the instrument board.

PRINCIPLE

The vapour-pressure type of thermometer, which is the one in common use, depends for its action on the fact that the vapour pressure of a pure volatile liquid depends only on the temperature of the liquid, i.e., for every temperature there is one definite pressure quite independent of the volume of the liquid (Fig. 6.) The complete instrument consists of a thermometer bulb, a transmitting tube, and a Bourdon-tube type of indicator,

the whole forming a sealed system almost completely filled with a volatile liquid. The temperature to which the thermometer bulb is subjected determines the pressure of the vapour in the bulb, and this pressure is transmitted through the capillary tubing and produces a movement of the bourdon pressure gauge and pointer. Some of the suitable liquids are ethyl-ether, ethyl-chloride, methyl-chloride, sulphur-dioxide and others, but ethyl-ether is the one most commonly used.

You will no doubt have noted two objections to this class of instrument being used, firstly, that the movement of the bourdon tube is dependent on the difference between the external and the internal pressures. The external pressure is that of the atmosphere, and since it is not practical to seal the pressure gauge case, it therefore decreases as the altitude increases. Thus, with the thermometer bulb maintained at a constant temperature, and the

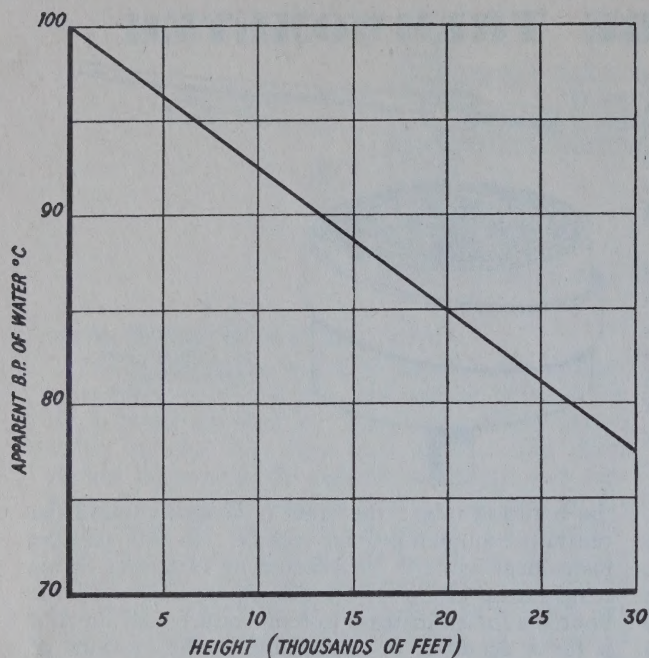


Fig. 5

internal pressure therefore constant, the pointer would move over the scale in the direction of an increase of temperature as the aeroplane climbed, due to the external pressure on the bourdon tube gradually becoming less and so producing a greater pressure difference. An instrument, for example, with the bulb at eighty degrees C. would read eighty-five degrees at 20,000 feet. Since the effect is always to cause the thermometer to over-read, the error is on the safe side and would be neglected, except that it affects the boiling points. The error is not large at the higher temperatures. The next difficulty that presents itself is that the temperature at which water boils depends directly on the pressure to which it is subjected. At normal atmospheric pressure of 14.7 lb. per square inch water boils at a temperature of 100 degrees C., and at a lower pressure the boiling point is lower. The water in the cooling system is subjected to atmospheric pressure, which decreases with increasing altitude. The temperature at which water boils will, therefore, be less than 100 degrees and will decrease with increasing altitude. To overcome this difficulty the boiling points of water for different altitudes are marked on the dial of the instrument in red, and the water will be boiling when the pointer registers against the boiling-point mark, corresponding to the altitude of the aeroplane. It will, therefore, be seen that the radiator temperature thermometer can only be used in conjunction with the altimeter or height indicator. The boiling points of water at different altitudes are shown in Fig. 5.

INSTALLATION

The capillary tube should be kept well clear of the exhaust manifolds and other heated parts of the engine; it should be clipped at intermediate points of its length to obviate damage by excessive vibration. The minimum radius of any bend allowed is 0.5 inches. Excess length of tube should be coiled in loops of not less than six inches diameter, taped together and clipped in at least three places to the aeroplane structure. Care should be taken when unwinding the capillary from the coil, as pulling it off in an axial direction will result in twisting it. On no account must the capillary be broken, disconnected or cut. A leak may generally be detected by the smell of ether in its vicinity.

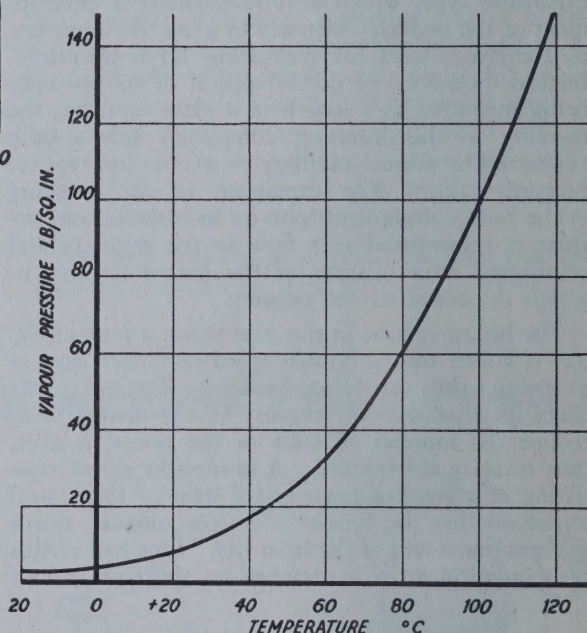


Fig. 6

CURVE SHOWING VAPOUR PRESSURES OF ETHYL ETHER AT VARIOUS TEMPERATURES

CALIBRATION

Calibration is effected by comparing with a standard thermometer at different temperatures. Precision thermometers with a metal protective sheathing are now supplied as master thermometers for this purpose. Each master thermometer has a certificate of examination by the National Physical Laboratory.

AIR SPEED INDICATOR

THE air-speed indicator is fitted to an aeroplane to indicate the speed at which the aeroplane is travelling through the air. It does not, of course, show the speed at which the aeroplane is passing a point on the ground, as that depends partly upon the speed of the air or wind relative to the ground. For instance, if the indicator showed a speed of 200 miles per hour, and the aircraft was flying into a head wind with a velocity of 40 m.p.h. the actual speed of the aircraft would be 160 m.p.h. If the wind were a following wind, the actual speed would be 240 m.p.h. This can best be remembered by noting that 40 m.p.h. (the head wind) would be registered upon the air-speed indicator when the aircraft was stationary on the ground.

The principle of the instrument, which is depicted in diagrammatic form in Fig. 2, is to take a measure of the difference between the pressure of the relative wind, due to the motion of the aeroplane through the air, and that of the surrounding still air. The pressure gauge, Fig. 3, consists of an airtight chamber, divided into two compartments by means of a sensitive diaphragm or capsule (1). One chamber is supplied with air at pressure, the other with static, or still air (3). The pressure must obviously be drawn from the outside of the aircraft and it is usual to fit a tube on the forward edge of the wing facing the direction of flight. It could be assumed that the static chamber could be filled from the still air in the cockpit or cabin of the aircraft. This is not so, inside the cockpit of an aeroplane in

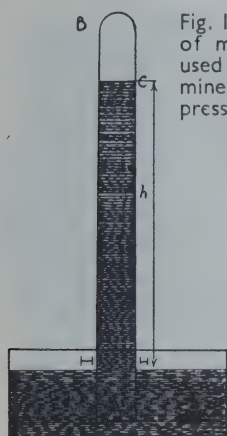


Fig. 1. A column of mercury is used to determine atmospheric pressure.

Fig. 2. Illustrating the "Pitot" flow meter principle.

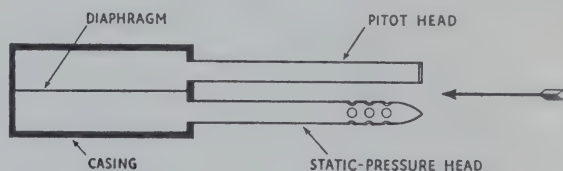
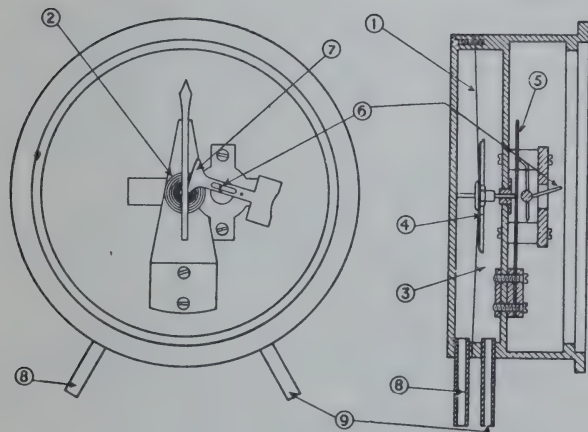


Fig. 3. Diagram showing construction of air pressure gauge.



flight, the air flow generally produces a region of low pressure, the extent of which depends on so many factors that it is essential for the instrument to be independent of it. For this reason the low pressure side of the instrument is connected to a second tube adjacent to the pressure tube, the pair forming what is known as the pressure head, Fig. 4. The pressure head is based on the same principle as that used by Pitot about the year 1730 for measuring the speed of a river. It will be noted that the static tube is closed at the end with a stream-lined brass plug, and that the tube is drilled with 24 radial holes one thirty-second of an inch diameter arranged in four rows. It has been proved by experiment that pressure inside the static tube is very nearly the true pressure outside whatever may be the velocity of the tube. The pressure or Pilot tube is open ended and unswept to prevent ingress of moisture. The more modern types of pressure head are fitted with a heater element to prevent the formation of ice, and a trap to seal the end against sand, insects, etc.

The construction of the indicator varies in detail, but they can be classified as either of the diaphragm type or of the capsule type. In the former type a circular diaphragm of leather, oiled silk or rubber

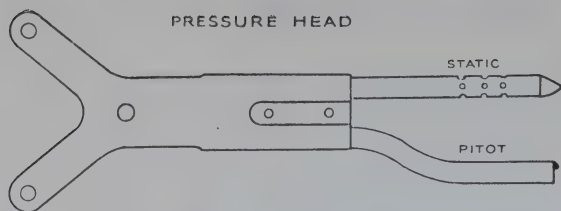


Fig. 4. Pressure Head using the Pitot principle

is stretched across the instrument case to form two airtight compartments, one of which is coupled to the Pitot tube and the other to the static tube as shown in Fig. 3. To the centre of the diaphragm (1) is fixed a disc (4) with a spindle which works axially in a guide. When the pressure causes distension of the diaphragm the end of the spindle

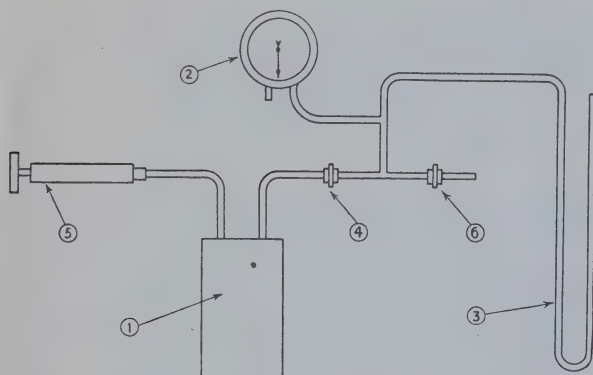


Fig. 5. Diagram shewing layout of Manometer

presses against a leaf spring (5) which is thereby deflected proportionally to the pressure. The leaf spring in turn acts on a bell-crank lever, (6), the other arm of which acts actuates a toothed quadrant (7) which meshes with a pinion on the pointer spindle. A hair spring is fitted to take up backlash in the mechanism. The pitot branch (8), and static branch (9) are shown.

A special type of manometer, calibrated in miles per hour, (knots in the case of seaplanes) is made to the Air Ministry specification, and is on the principle of the old type manometer as shown in Fig. 5. Pressure from the air reservoir (1) can be supplied to both the manometer and the instrument under

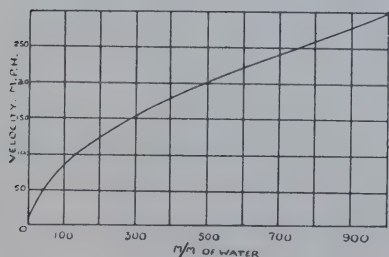


Fig. 5a.

test (2) by means of the T joint. The manometer tube (3) is filled with water to a zero level, and the tap (4) is then closed. By means of a hand pump (5) pressure is built up in the reservoir. By means of cautiously opening the tap, pressure can be built up in the instrument and the manometer at the same time. The arms of the U tube have a card behind them marked out in vertical millimetres, and the error of the instrument may be found by referring to the curve, Fig. 5A. The tap (6) is for the purpose of reducing the pressure when calibrating an instrument down the scale.

A complete air-speed indicator is shown in Fig. 6 and is made by Smiths Aircraft Instruments, Ltd., it will be noted that the dial is calibrated in tens of miles per hour, and that the dial has a double scale, the pointer making one and a half revolutions.

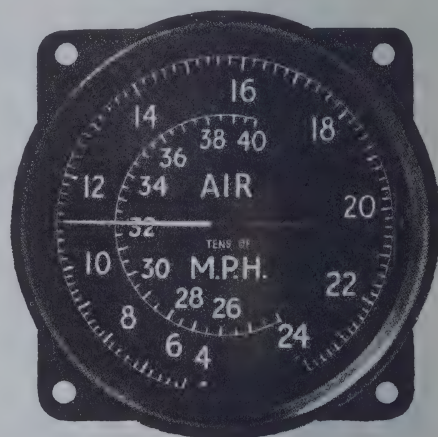


Fig. 6. Smiths Air Speed Indicator

If a pressure equivalent to 130 m.p.h. is applied to the pressure chamber and then shut off, the leakage to the static side or atmosphere must not cause the reading to drop more than 10 m.p.h. 10 seconds.

The case or static chamber should withstand a pressure of 1 pound per square inch without showing any leaks when immersed in water.

Difference of reading at any part of the scale due to a change of position of the instrument between vertical and horizontal planes should not exceed 1 m.p.h.

As in all aircraft instruments, readings should be taken both up and down the scale slowly to avoid errors due to lag.

It is important that the above tests should be carried out under a standard temperature. I once had the pleasure of being conducted round Smith's Aircraft Instrument Works and noted that an air purification and temperature control system was then being installed.

During the above tests light tapping of the instrument is permissible as a certain amount of vibration is transmitted to them from the engine.

coloured red, provided to indicate the maximum permissible "boost" pressure for the particular engine to which the gauge is connected.

The boost gauge is connected to the exhaust manifold of the engine by means a $\frac{1}{8}$ -inch B.S.P. union threaded through the rear of the case from inside and made secure with a lock nut; except for this the case is airtight. The gauze filter fitted inside the union should be removed periodically and washed in benzine. In the older types of boost gauge special petrol resisting synthetic rubber washers were fitted between the bezel and the glass, and the glass and the case flange; the new type Negretti & Zambra Mark III instrument eliminates this joint, enabling the airtightness of the case to be maintained indefinitely without attention.

It is a mistake to assume that the boost gauge should always read zero when not connected to an engine, or when the engine is not running. Having an evacuated capsule the instrument is an absolute pressure gauge and the pointer should stand at "0" only when the surrounding atmosphere is at "London Laboratory Conditions," *i.e.*, at a latitude of 51° deg. and a temperature of 16.6 deg. Cent. "0" therefore equals a pressure equivalent to a column of mercury 29.994 inches in height, and taking this as a standard the boost gauge may be calibrated with a mercury type manometer, the scale being marked out according to the following table:

**Note.* ("London Laboratory Conditions" should not be confused with "Standard Barometric Pressure"),

Mercury column in inches.	Readings of Boost Gauge lb./sq. in.
21	—4.40
23	—3.32
25	—2.44
27	—1.46
29	—0.38
29.994	0
30	+0.03
32	+1.01
34	+1.99
36	+2.97
38	+3.95
40	+4.93

To calibrate the minus readings on the boost gauge it will be necessary to have a minus pressure, *i.e.*, less than 30 inches of mercury, assuming that the calibrator is on the principle illustrated on page 172. (Air Speed Indicator), the chamber (1) instead of being filled with air under pressure by means of the pump (5) will have to be evacuated of air, this would of course entail altering the pump piston to exhaust instead of inflating. Opening of the tap (4) would cause a reduction in height of the right hand scale of the "U" tube with a corresponding lift in the mercury level in the left hand leg of the tube.

It should be borne in mind that an increase or decrease in pressure of say one inch would be shown as half an inch of movement in each leg of the "U" tube, *not one inch in each leg.*

ATMOSPHERIC PRESSURE

AS the performance and calibration of many aircraft instruments is very closely linked up with atmospheric pressure, it would be wise if at this stage we take a brief review of the principles involved.

It will be useful to recall the elementary fact that air has a weight of approximately 1.293 ounces to a cubic foot. Suppose we take a glass tube about three feet long, sealed at one end B (Fig. 1) and open at the other end A. Fill the tube carefully with pure liquid mercury, invert it, and then place it perfectly upright in a vessel of mercury whose upper surface is exposed to the atmosphere, care being taken that the open end of the tube is kept beneath the level of the mercury in the vessel. It will be found that the mercury in the tube will descend to a point C, which is 30 inches from the level of the mercury in the vessel.

HOW IT IS MEASURED

The space between the top of the mercury at C and the end of the tube at A may be considered a perfect vacuum. (There may be only a small amount of vapour pressure due to the vaporization of the mercury but it will be so slight that we can afford to ignore it), and so therefore there will be no air pressure on the top of the column of mercury at C. The pressure on each square inch just inside the tube at H is equal to the weight of the superincumbent 30 inches of mercury. And the pressure at H inside the tube is the same as the pressure at H outside the tube at the surface of the mercury in the vessel, because the pressure of a heavy homogeneous fluid like mercury is the same at all points in the same horizontal plane; but the pressure on the surface of the mercury in the vessel is that of the atmosphere above it.

Given the height of the column H to C and the cross-sectional area of the bore of the tube, we can calculate the weight of the mercury in the tube. One cubic inch of mercury weighs .491 pounds; thus if the bore of the tube has a cross-sectional area of one square inch and the column of mercury is 30 inches in height, the weight of the column will be $30 \times .491$ which is 14.7 pounds approximately, that is the pressure at S inside the tube is 14.7 pounds per square inch. This then is the pressure produced by a column of air one square inch in cross-section and about five miles in height, providing the air has the same density at all altitudes as

at the surface of the earth. Actually the air becomes less dense with increasing altitude so that the column of air producing a pressure of 14.7 pounds per square inch at sea-level is probably from 150 to 200 miles in length.

If the bore of the tube was only $\frac{1}{10}$ or $\frac{1}{100}$ of a square inch in area, the pressure exerted at S would be 1.47 and .147 pounds respectively, and the column of air supporting the tube of mercury would be 200 miles in length and $\frac{1}{10}$ or $\frac{1}{100}$ of a square inch respectively. Thus the pressure intensity is the same no matter what area of mercury column is used, that is about 14.7 pounds per square inch.

THE AIR MINISTRY STANDARD

If careful observation be made of the mercury column it will be found that the height is continually changing, it follows therefore that the atmospheric pressure is continually changing. It is, in general, less when the atmosphere has in it a large quantity of moisture; it is greater at the bottom of a mine shaft, and less at the top of a mountain, than at the earth's surface. Again variations in the temperature of the mercury will be manifested as a movement at C, obviously therefore when stating the atmospheric pressure it will be necessary to give the height above sea level, the temperature, and the particular meridian. The Air Ministry state that "Standard Barometric Pressure" (S.B.P.) or "Standard Mercury," is "that pressure which will support a column of pure mercury 29.921 inches in height at a temperature of 0 deg. Cent., at sea-level, and at a latitude of 45 deg."

A simple experiment with atmospheric pressure: A-B is a tube of mercury inverted, with the open end, A, below the surface of a vessel of mercury, H. C is the level in the tube to which the mercury falls. The distance from H to C is thirty inches. Given the bore of the tube the weight of the mercury in the tube can be calculated.



THE CROSS-LEVEL

THE primary function of the cross-level is to indicate the inclination of the lateral axis of the aeroplane. This instrument is invaluable when flying blind.

As will be seen by Fig. 9, the cross-level consists of a glass tube containing a non-freezing liquid and an imprisoned bubble. The whole mounted in a duralimin or plastic frame with divisions of 10 and 20 degrees from the vertical cast on. As the liquid is of a greater density than the bubble, the latter will always be at the highest point of the glass tube when the tube is stationary. When the aircraft banks the tube tilts and the bubble will move to the highest point. The position of the bubble with regard to the centre of the curved tube gives therefore a measure of the direction of the resultant forces when the aircraft is in motion.

Although the primary function of the cross-level is to show whether the wing tips are level or not, it will be obvious that it will react to certain forces in the same manner as a pendulum, *i.e.* :

(1) When acted upon by gravity only, if one wing is low the bubble will move to the highest end of the glass tube.

(2) If the aircraft is making a correctly banked turn, the effect of the centrifugal force will cause the resultant force to act in a direction perpendicular to the wingspan and the bubble will remain central, just as would a pendulum remain perpendicular to the datum plane.

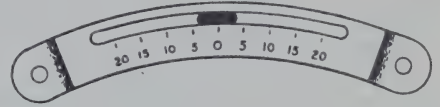
(3) Should the plane be insufficiently banked, it will side-slip outwards in the same manner as an automobile would if driven fast round an unbanked corner with a greasy surface road. The resultant

of the centrifugal force and the weight no longer acts perpendicularly to the wing span but is inclined outwards. Since a pendulum would put itself in the line of this resultant it follows that the bubble of the cross-level will move inwards.

(4) In an over-banked turn the aeroplane will slip inwards. The bubble will therefore move outwards.

In an endeavour to avoid side-slip the control must always be moved in the direction of the bubble. Hence the old flying rule : "Follow the bubble."

Fig. 9.
The Cross-
Level,
indicating
an even keel.



The cross-level is mounted on the instrument board so that when the aeroplane is in flying position (tail up) the bubble is central to the zero line. Where space and layout of instruments permit, the level should be placed on a level with the pilot's eye.

In tropical climates where wide ranges of temperatures are experienced, a type of cross-level is fitted with an expansion bulb connected by a short capillary tube to one end of the level tube. Under normal room temperature, 10 deg. Cent. to 20 deg. Cent., the expansion bulb is about one third full and the proportions of bulb, capillary and liquid content are so chosen that expansion or contraction of the liquid under extremes of temperature does not materially affect the size of the bubble. (Usually about half an inch).

THE LONGITUDINAL CLINOMETER

THE fore-and-aft level, or longitudinal clinometer is fitted on aeroplanes to give an indication of the angle between the longitudinal axis and the horizontal. It is occasionally referred to as the Gradometer.

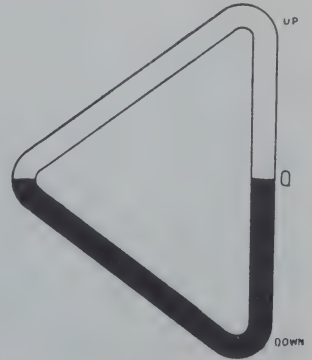
A Mark II fore-and-aft level is shown in Fig. 10. It consists of a glass tube worked into triangular form, one side of the triangle forming the front of the instrument. The bottom corner of the triangle is enlarged to form a reservoir and surging of the liquid is damped out by means of a constriction in the lower limb.

When the nose of the aeroplane rises the level of the liquid rises, and when the nose drops, so does the level of the liquid.

During sudden changes in inclination, namely acceleration or the reverse the instrument will not give reliable readings, but can only be relied upon when the aeroplane is in steady motion. If a spirit level is suddenly slid along the surface of a table,

the bubble will move in the direction of the motion of the level until the motion has become steady. On stopping the level suddenly, the bubble will move slightly in the opposite direction.

Fig. 10. The fore-and-aft level, or Gradometer, employing the same elementary principle as the spirit level.



THE FUEL CONTENTS GAUGE

THE electric fuel contents gauge indicates the amount of fuel in the tank, or tanks, of an aircraft by means of a dial and pointer on the instrument panel.

A varnished cork float, Figs. II, (a and b) resting on the surface of the fuel determines the position

When the potentiometer arm is central the current in coils A and B will be equal and there will be no current in coil C.

The armature is not spring controlled and will therefore take up its position along the magnetic field, *i.e.*, parallel to the axis of A and B as illus-

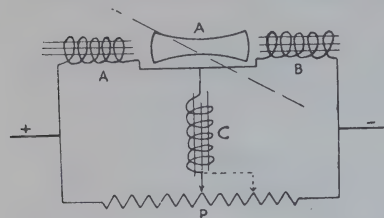


Fig. 10. A detailed diagram of the electrical circuit of the fuel contents gauge.



Fig. 12. A sketch of the potentiometer controlled by the fuel level.

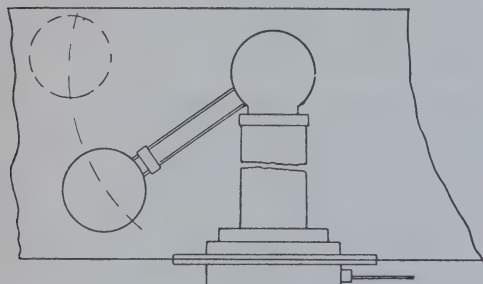


Fig. 11a. Diagram illustrating the rise and fall of the float controlling the potentiometer.

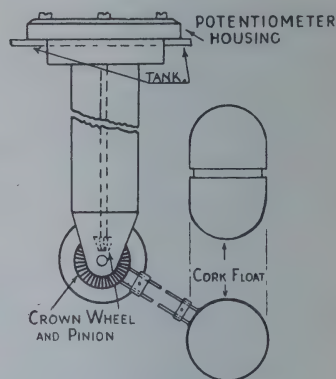


Fig. 11b. Showing how the float operates the potentiometer arm by means of a crown wheel.



Fig. 13. A dial showing fore-and-aft level incorporated with the fuel-contents gauge

Fig. 15. An indicator switch controlled, giving fuel contents of two tanks.

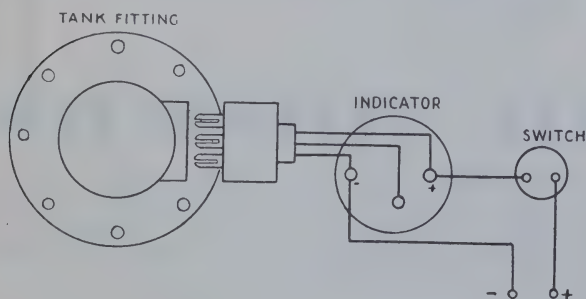
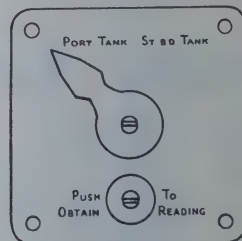


Fig. 14. The wiring circuit of the switch-operated indicator shown in fig. 15. By this means the contents of any number of tanks can be indicated.



of the contact on the potentiometer, Fig. 12, and the electrical circuit is so arranged that the pointer of the indicator, Fig. 13, follows the movement of the potentiometer arm.

The contents of any number of tanks may be indicated on one dial by means of the selector switch and push button, Fig. 15.

The circuit is shown in Fig. 10, the potentiometer (P) is connected across the 12 volt supply and in parallel with it are two coils, A and B connected in series. The third coil C is connected to their mid-point and the moving blade of the potentiometer. A soft iron armature A is pivoted between the coils.

Should the potentiometer arm be moved by the float to a position left of the centre as illustrated by the dotted line, a current will flow through the Coil C, distorting the magnetic field round the armature and some of the lines of force will now link with C and the armature will be pulled round so that its axis lies in the direction indicated by the dotted line. It will be noted that movement of the armature, (and of course the pointer) is dependent on the ratio of the current in the coils and is therefore not affected by variations of voltage.

Note that indicator gives two readings: 'Tail on ground' and 'Normal flight, fore-and-aft level zero.'

THE ALTIMETER

IT may seem that I have dealt with this subject rather briefly but we are mainly interested in the repair and calibration of instruments and space does not permit of us going too deeply into their theory. Books by the score have been written on this interesting subject and if the reader desires to make a study of it he will have to visit his public library. Several well known physical laws will have to be mastered and a good knowledge of physics and mathematics will be necessary.

The altimeter may be referred to as an aneroid, being practically identical in construction and operation, having an evacuated capsule, Fig. 16. (1), supported by a spring (2) to prevent it collapsing through the pressure of the atmosphere. The capsule is secured underneath by the base plate of the movement (3) and on top by the spring (2).

TEMPERATURE COMPENSATION

Any change in atmospheric pressure causes expansion or contraction of the capsule, this in turn moves the spring and by means of the bell crank lever (4) and chain (5) moves the pointer (6). A hair spring (7) is fitted to keep the chain tight and to take up backlash in the mechanism. Compensation for varying temperatures is effected by means of the steel or Invar strip (8) fitted to the brass connecting lever (9). A change of temperature will change the elasticity of the spring and capsule, so causing a pointer movement without a change of pressure. The different coefficients of expansion of the bi-metallic strip cause the lever to bend and thus counteract the movement of the capsule and spring. (This bi-metallic compensating device will be found in nearly all aircraft instruments of the dial and pointer type). The extreme variations of temperature that aircraft have to contend with, 30 degrees Cent. or more in hot climates, on the ground, to as low as -40 degrees Cent. at high altitudes in winter, make temperature compensation of great importance.

ITS USES AS A WEATHER PREDICTOR

It is impossible to compensate the altimeter for varying atmospheric conditions, and so, if it indicates say, 2,000 feet above sea-level, it means 2,000 feet above sea-level if the atmospheric conditions are standard, that is, according to theory; high and low pressures being indicated as changes of altitude.

Since the barometric pressure is constantly changing, the altimeter may be set on the ground to read zero, and a few hours later will not read zero. This change of ground barometric pressure often amounts to the equivalent of half an inch of mercury, corresponding to approximately 500 feet altitude, and sometimes as much as an inch.

An aneroid altimeter may be used as a weather

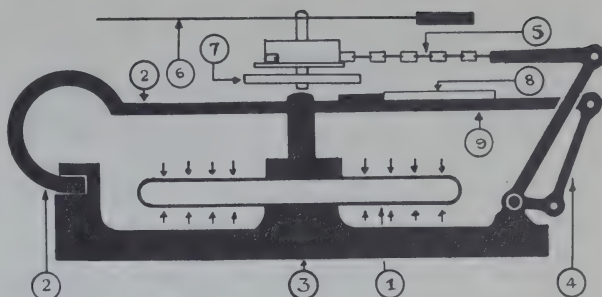


Fig. 16. Diagram of an altimeter, showing the capsule (indicated by small arrows) which controls the movement.

predictor, by leaving the zero adjustment unchanged. This would also enable the altimeter to be checked, if the aneroid altimeter indicated a higher altitude than the true, it would show that the barometer had fallen, and vice versa. I believe this method was actually used on the ill fated airship R.101. Another lighter than air method used to find the true altitude above water, was to drop plaster of Paris eggs and count the time from the instant they were released until they could be seen shattering on the water.

CHECKING AN ALTIMETER

We have learnt that an altimeter is an aneroid barometer with its dial graduated on a height scale based on an assumed relationship between atmospheric pressure and altitude. We have learned also that the most accurate type of barometer is the mercury column. The mercury column is therefore used as a check for the capsule type altimeter.

The standard method is to place the altimeter to be tested in a metal chamber having an observation window and fitted with a hand pump to evacuate the air (Fig. 17). The mercury column is connected direct to the chamber and has a scale behind it, marked out in inches or millimetres on

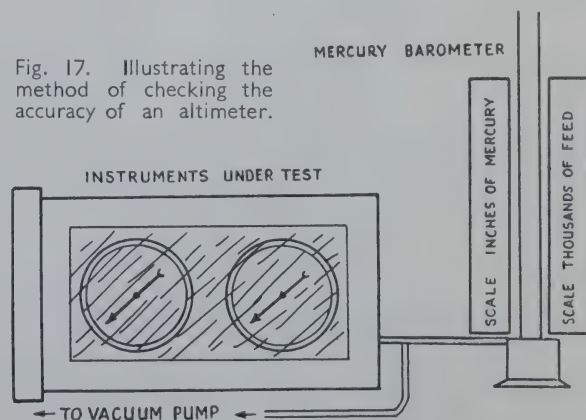


Fig. 17. Illustrating the method of checking the accuracy of an altimeter.

one side and equivalents of thousands of feet on the other. As the air in the chamber is gradually exhausted by means of the hand pump. The vacuum pressure to which the mercury column is subjected will be the same as that in the chamber containing the altimeter under test. By gradually exhausting the chamber of air the pressure effect of increasing altitude will be obtained and the accuracy of the altimeter may be checked by comparing the reading of the altimeter and the mercury column at different pressures.

Owing to the lag of the capsule in readjusting itself to different pressures, an altimeter should be calibrated slowly, about a thousand feet per minute, up and down the scale is a good standard.

AN ALTERNATIVE METHOD

The interior of the chamber is fitted with grooves, in which the panel carrying the altimeter under test slides. If desired an accurate sub-standard altimeter and a repaired instrument may be mounted side by side and the readings compared.

Some basis as to the variation of pressure with height has to be agreed upon. Further, no assumptions can be made which will apply to the temperature conditions at the time of observation of the altimeter. In use the altimeter must be corrected to the temperature by means of an Air Temperature Thermometer and a computer. The computer consists of a plate about six inches in diameter, engraved with two scales, temperature and height. Another disc, smaller, carries logarithmic scales and can be rotated by means of a milled knob.

The two methods of calibrating altimeters are :

THE ISOTHERMAL CONVENTION

This assumes that the temperature at all heights is constant at 10 degrees Cent., the pressure varying with height according to the following formula :

$$H \text{ is } 62.58 \log_{10} \frac{P_2}{P_1}$$

Where H= is height in thousands of feet.

Where P_1 = is pressure at H.

Where P_2 = is pressure on ground.

THE I.C.A.N.† CONVENTION

This assumes that the temperature falls at the uniform rate of 1.98 degrees Cent. per thousand feet from 15 degrees Cent. at sea-level to -15 degrees Cent., and is as follows :

$$\frac{P_2}{P_1} \text{ is } \left\{ \frac{288}{2888 - 1.9814} \right\}^{5.256}$$

Where P_2 = ground pressure in millibars* (101.2 mbs).

„ P_1 = pressure at H in millibars.

„ H = height in thousands of feet.

„ P_3 = pressure at 36,090 feet, calculated from the formula.

Above 36,090 feet the following formula is used :

$$H = 36,090 + 47,900 \log_{10} \frac{P_3}{P_1}$$

† International Commission for Air Navigation.

* A millibar is one thousandth part of a bar, a bar being a unit of barometric pressure having a value of 29.53 inches of mercury at 0 degree Cent., at sea level and at a latitude of 45 degrees.

RATE OF CLIMB INDICATOR

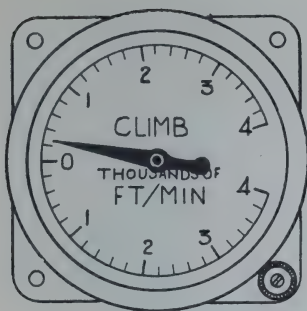


Fig. 1. A sketch of the dial of the rate-of-climb indicator, calibrated in thousands of feet per minute.

THIS indicator, a front view of which is shown in Fig. 1, is a sensitive differential pressure gauge, showing pronounced rates of departure from level flight. Used in conjunction with other instruments it is invaluable for "blind flying."

The principle adopted is to measure the pressure difference of air on either side of a choke or restriction, the space on one side having a known capacity, and the other side being subject to air at static pressure. If the pressure is changed on the latter side to simulate the change of static pressure as when climbing, the rate of climbing may be determined by measuring the pressure drop across the restriction.

The principle is shown diagrammatically in Fig. 2. Another type of rate climb indicator has a case that is leak tight to form a capacity. The capsule is a flexible wall to the capacity, and the outer surface of the capsule is subject to the pressure within the capacity. The inside of the capsule is subject to static atmospheric pressure.

A knob marked "Zero return" fitted to the front of the instrument case enables the pressure in the chambers to be equalised after a climb by turning the knob anti-clockwise. The knob must then be turned clockwise to close the valve connecting the chambers, to leave the instrument ready for use.

The instrument is fitted with the usual bell-crank mechanism, hair-spring and bi-metallic temperature compensating device.

This indicator is very sensitive and liable to inaccuracies developing due to excessive overloads as a result of power dives.

At normal temperatures the errors should not exceed plus or minus 200 ft. per minute, and the instrument should be capable of withstanding extremes of temperatures from minus 40 deg. cent. to plus 60 deg. cent. without derangement.

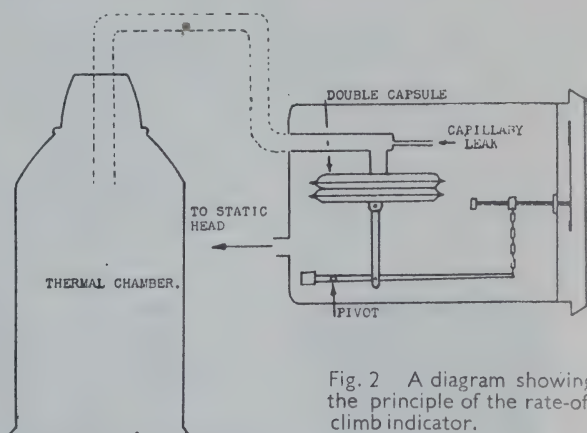


Fig. 2. A diagram showing the principle of the rate-of-climb indicator.

THE ALTITUDE RECORDER

ALTIUDE recorders are used on aircraft to record altitude on a time base and are invaluable for ascertaining rate of climb from take off to maximum height.

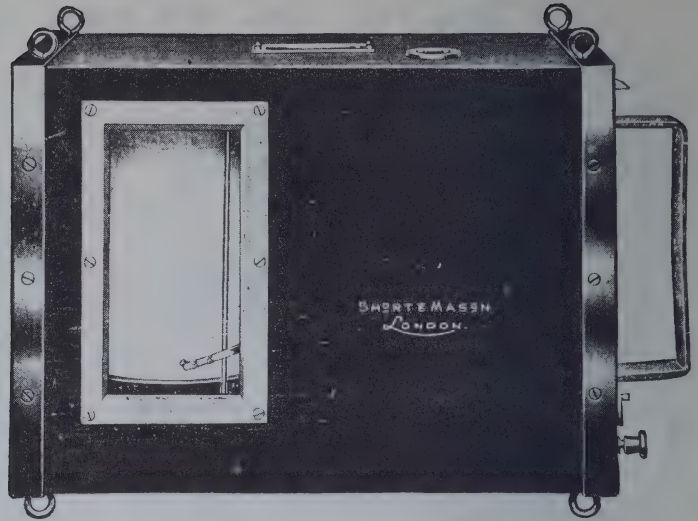
The recorder utilises an aneroid mechanism to move an ink pen across a paper covered drum. Rotation of the drum is effected by a clock mechanism and the chart has a base line marked in minutes and a vertical scale marked in thousands of feet. The clock drive is transmitted to the drum by means of a friction clutch so tensioned that no slip occurs when the drum is rotating in operation but

which allows of it to be turned by hand for setting to position. The clutch may be released and the drum removed to facilitate the fitting of a new chart.

Two views of the instrument are given in Figs. 3 and 4. Fig. 3 shows the complete instrument and Fig. 4 shows the instrument withdrawn from its case.

The aneroid near the centre of the instrument is mounted on a brass plate which also carries two pairs of brass pillars. The pair remote from the drum carries a horizontal rod. The aneroid mechanism is coupled to the rod by a connecting

Fig. 3. The Short & Mason altitude recorder, complete in case. It is suspended, when in use, by four elastic bands, above and below.



link in such a way that a turning movement is given to the rod, which in turn moves the pointer and the pen over the scale. The other pair of pillars carries the bearing for the connecting link. A spring and a balance weight serve to damp out oscillations of the pointer.

Two adjusting screws are provided one of which varies the pressure of the pen upon the

drum and the other enables the correction to be made to the zero setting. A knob operates the penshift, lifting the pen clear of the scale and at the same time stopping the clock mechanism.

When installing the instrument in an aeroplane it should be suspended by four electric bands above and supported by four below. Rings for the fixing of these will be seen in Fig. 3.

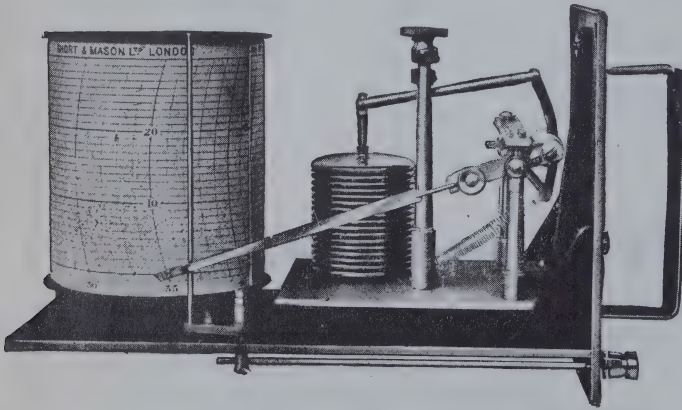


Fig. 4. The Short & Mason altitude recorder withdrawn from the case. The mechanism transmitting movement from the aneroid to the pen is clearly seen.

AIR SPEED RECORDER

THE Air Speed Recorder is used on aircraft to record speed on a time base and in particular to secure a record of speeds attained by the aircraft over a period such as 30 minutes.

The recorder utilises a standard air-speed indicator mechanism, which moves an ink pen across a paper chart clipped round a drum. The drum rotation is effected by a clock mechanism and the paper chart has a base line marked out in minutes and a vertical scale marked out in miles per hour. The clock drive is transmitted to the drum by means of a friction clutch so tensioned that no slip occurs when

the drum is rotating in operation but which allows of it being turned by hand for setting to position. The clutch may be released and the drum removed to facilitate the fitting of a new chart.

Fig. 5 shows the instrument withdrawn from its case.

The pressure and static chamber capsule from which two tubes lead to the nipples P and S on the end of the instrument is mounted in an aluminium frame which incorporates bearings in which the rod is carried. The mechanism of the capsule is coupled to the rod by means of a collar and

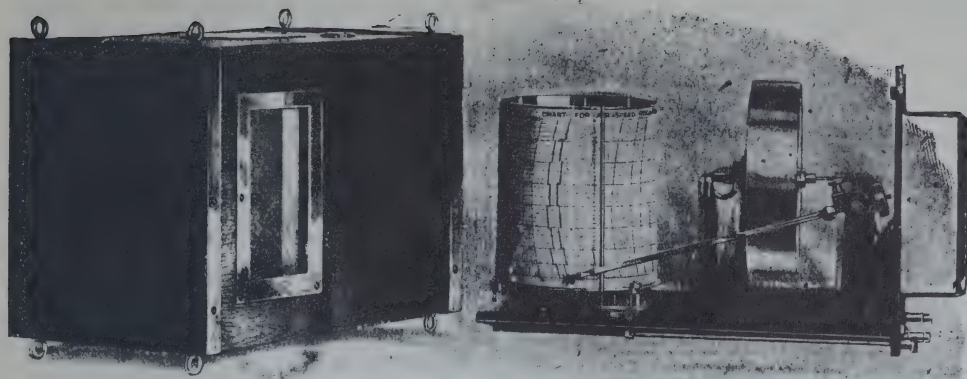


Fig. 5. An air-speed recorder (Short & Mason) withdrawn from its case to show details of mechanism. In use it is suspended similarly to the rate-of-climb indicator.

spring in such a way that it imparts a turning movement to the rod which in turn moves the pointer and the pen over the scale.

Balance weights are provided on the rod for the purpose of calibration. A knob operates the pen shift lifting the pen from the scale and at the same time stopping the clock mechanism.

Two adjusting screws are provided; one varies the pressure of the pen on the drum and the other enables the pen to be moved through a short vertical distance to obtain the zero setting.

When installing the instrument in an aircraft it should be suspended by four elastic bands above and supported by four below.

THE COMPASS

THE primary function of a compass is to show in which direction the magnetic north lies, and to do this the compass makes use of the property of the poles of a magnet to attract and be attracted by the opposite pole of another magnet. The earth itself being magnetised, a freely suspended magnet will take up a position with one of its poles pointing towards one magnetic pole of the earth. The two magnetic poles of the earth are near to the geographic North and South poles and the pole of a magnet that tends to point towards the North pole is called a North-seeking or N pole. To avoid confusion with the North pole of the earth, which is of the same kind as the South seeking pole of a magnet, North-seeking poles are designated RED poles and South-seeking poles BLUE poles, and magnets are frequently coloured accordingly.

An aircraft compass consists of a magnet or a group of magnets rigidly attached to a frame suspended on a pivot at centre. A magnet freely suspended at its centre of gravity so as not to be affected by gravity will however generally take up a position at an angle to the surface of the earth, and the magnet system of a compass is therefore suspended at a point above its centre of gravity so that its weight will keep it almost horizontal and the red pole will point along the surface of the earth towards the magnetic North, that is along the magnetic meridian.

A compass with such a suspension and installed in an aeroplane in steady straight flight will indicate the magnetic North accurately, but if the aeroplane is turning or accelerating, the magnet system will have other forces acting on it. These forces can be

considered as acting entirely at the centre of gravity of the magnet system. Owing to the slight tilting of the magnets by the earth's magnetism the centre of gravity is not generally exactly vertically below the point of suspension, and the forces will therefore exert a turning action on the magnet system, which will deviate from the direction of the magnetic field. For this reason compass readings are not reliable when the aircraft is turning or accelerating.

The magnetic conditions in an aeroplane are particularly unfavourable to the use of a compass owing to the presence of large masses of magnetic material and of electric circuits. A certain amount of permanent magnetism is set up in the magnetic material, and induced magnetisation produced by the earth's field and changing with the orientation of the aircraft is also present. Correction can be made for the permanent magnetism and part of the induced magnetism by means of small permanent magnets placed near the compass, and the deviation produced by other parts of the induced magnetism is measured for all headings of the aeroplanes and allowed for when reading the compass.

With these corrections the steady reading of a compass is sufficiently accurate for navigational purposes, but it should be borne in mind that there are deviations that cannot be corrected. The firing of a cannon such as is fitted to modern aircraft may considerably change its magnetism and the switching on or off of an electrical circuit may produce a change of magnetic field sufficiently strong to influence the compass.

The reliability of a compass therefore depends not only on the efficiency of the compass itself, but

also on the choice of its position in the aeroplane and the spacing of magnetic parts and electrical circuits from it, particularly those liable to changes. It also depends on the adjustment of the corrector magnets and the accuracy of the measurement of residual deviation, and on an understanding of the principles and limitations of the compass itself.

All compasses consist essentially of a magnet system suspended horizontally as described above, and the remaining parts of the compass are concerned with such practical considerations as the suspension of the system, the prevention of oscillation, etc.

In compasses used in aircraft the magnets are suspended in a bowl filled with liquid and sealed with a glass plate across the top. The liquid damps the movement of the magnets so that a steady reading can be obtained, and radial wires are usually fitted to the moving system to increase the damping. A secondary effect of the liquid is to reduce the weight on the pivot. The pivot consists of a hard-pointed screw resting on a jewel supported in the centre of the bowl.

The position in which the compass is installed in an aeroplane is decided upon during the design of the aeroplane, and cannot be altered. Each compass is placed as far as possible from magnetic materials and electrical circuits. All screws, bolts, nuts and other fittings used on or about the compass must be of non-ferrous material and no magnetic material should be allowed to come within eighteen inches of the compass.

The complete inspection and testing of a compass

is not practicable, but all compasses are thoroughly tested by the makers immediately prior to despatch. Apart from mechanical damage which it may suffer in transport or in use, the compass will in time become unserviceable from wear and deterioration, and examination must be made with particular attention to the following requirements:

1. The bowl must be completely filled with liquid.
2. The liquid must be free from discoloration and bubbles.
3. The pivot should be free from friction.
4. The suspension of the bowl in the container must be in good condition.
5. If the compass is installed in an aeroplane the corrections must be accurate.

The liquid normally used in aeroplane compasses is a mixture of pure alcohol and distilled water and it is essential that the correct mixture is used.

Excessive friction at the pivot of the magnet system may develop gradually or it may be caused by mechanical shock. To test for pivot friction the magnet system should be deflected about ten degrees by placing a piece of magnetic material near it, it should be held in this position until the liquid comes to rest. It should then be released and careful note should be taken of the difference of reading from the previous setting, no tapping or vibration should be applied during this test.

In general the pivot friction of a compass should not exceed two degrees.

GYROSCOPIC INSTRUMENTS

THE gyroscope in its simplest form is not a modern invention, it is quite a century and a quarter old. Who, years ago, would have dreamed that in this simple apparatus lay concealed the secret of steering a torpedo; of steadying a vessel; of finding one's position in the air and at sea; of proving the rotation of the earth; of finding the true North; and of flying machines automatically stable?

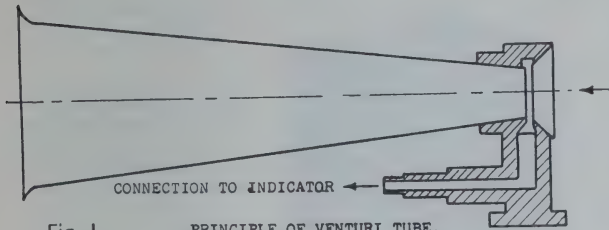


Fig. 1. PRINCIPLE OF VENTURI TUBE.

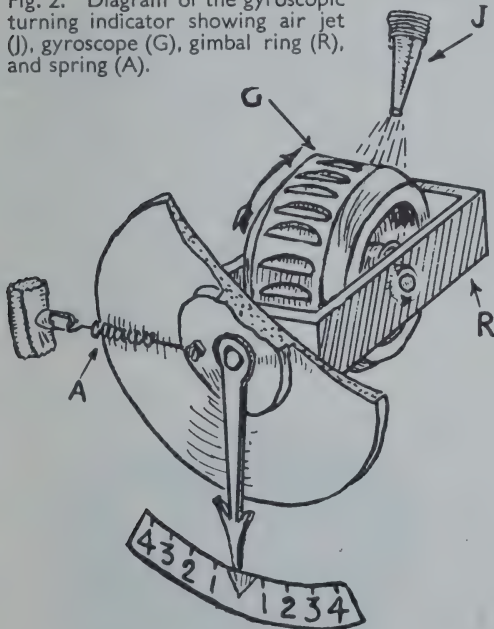
The following aircraft instruments make use of the gyroscope: The Directional Gyro; The Artificial Horizon; The Turning Indicator; and The Gyropilot.

Most gyro instruments are operated by suction produced by a Venturi tube, (Fig. 1), acting on the principle of the injector on steam engines, the Venturi tube is placed in the slip-stream with the small end pointing in the direction of flight, the flow of air through the tube causes a reduction of pressure at the side aperture which is connected by tubing to the air-tight case of the instrument. The suction created by the reduced pressure causes a partial vacuum in the case which is equalised by air being drawn from the outside of the case through a jet, which impinges on the buckets cut in the periphery of the gyro wheel (Fig. 2). Wherever possible the use of an engine driven pump is recommended in the place of the Venturi tube.

THE TURNING INDICATOR

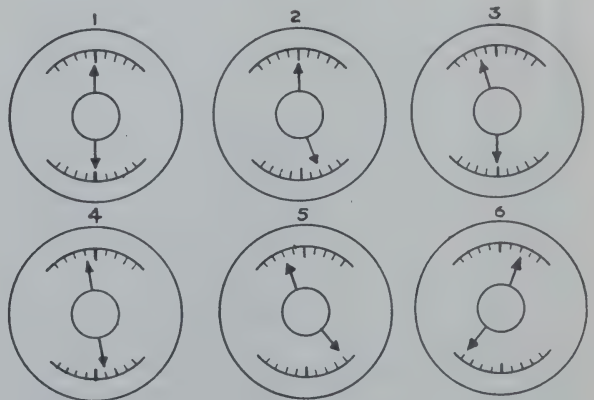
THE turning indicator is designed to assist the pilot in keeping a straight course and to give him a clear indication of departure from normal flight when the horizon and ground are not visible.

Fig. 2. Diagram of the gyroscopic turning indicator showing air jet (J), gyroscope (G), gimbal ring (R), and spring (A).



The principle of the instrument is shown in Fig. 2., an air driven gyroscope (G), is mounted in a horizontal gimbal ring (R), the axis of the gyroscope being athwart the aeroplane, and the gimbal ring axis fore-and-aft. When the aircraft turns, the movement corresponds to rotation of the instrument in a horizontal plane, and a precessing torque is applied to the gimbal ring about the gimbal axis, causing the gimbal ring to 'topple.'

Fig. 3. Six readings of the indicator: 1 Straight flight, 2 Turn to right (banking correct), 3 No turn (side-slip to left), 4 Turn to right (side-slip to left), 5 Right spin, 6 Left spin.



The gimbal ring, being spring controlled, comes to rest in a position of equilibrium when the precessing torque balances the tension in the spring (A). The movement of the gimbal ring, suitably damped, is indicated by means of a pointer on a scale on the front of the instrument.

It will be noted that it is the rate of turn which is indicated, or the ratio of the amount of turn

to the time taken for the turn. The advantage of this is that a sudden sharp turn, *i.e.*, a small turn taken in a short time would give a large reading on the indicator, whereas the compass would give no indication. The pilot would therefore be able to make corrections before the turn became excessive.

Fig. 3 gives six examples of instrument indications.

THE DIRECTIONAL GYRO

THE Directional Gyro, Figs. 4 and 5 is basically a free gyro, having an horizontal axis and provided with an azimuth card and setting device. The gyro (1) spinning about its horizontal axis H-H is universally mounted, *i.e.*, it is supported in a gimbal ring (2) which is free to turn about the axis G-G on bearings in the vertical ring (3). The vertical ring is free to turn about the vertical axis V-V. The circular card (4) which is attached to the vertical ring is observed by the pilot through a rectangular opening in the front of the case. When spinning the gyro obeys a fundamental gyroscope principle, *i.e.*, rigidity. Thus the rotor and the gimbal ring and the card which is attached to the vertical ring remains fixed in azimuth and *the aeroplane moves round them*. The card is observed in relation to a lubber line on the front of the instrument in the same manner as a compass. The caging knob (5) is used to set the card of the Directional Gyro to coincide with that of the magnetic compass and to reset it at periodic intervals. When this knob is pushed in it engages the synchroniser pinion (6) with the synchroniser gear (7). The operation of the caging mechanism which holds the gyro upright when the card is reset is as follows:

Pushing the caging knob IN engages the synchroniser lever plunger which normally rests in the cone-shaped interior of the pinion, and raises the lever pins (8) which slide in the groove (9) of the synchroniser ring. This lifts the synchroniser ring, pushing up the spring plunger (10) and raising the caging knob (11) so that it makes contact with the bottom of the gimbal and holds the gyro horizontal as the card is turned to the desired heading. Pulling the caging knob OUT releases the caging mechanism and leaves the gyro horizontal and free. The air jets of the nozzle (12) which spin the rotor, also serve to keep it upright. The air is divided into two parallel jets, each striking the buckets in the rim of the gyro at points equidistant from the centre. If the rotor tilts, the air from the jet on one side strikes against the rim instead of against the buckets, causing the rotor to return to its original position.

The average drift of the instrument card from its original setting is 3 degrees 15 minutes. This accuracy has been achieved by extremely careful design and workmanship which have resulted in great perfection of balance and a minimum of friction.

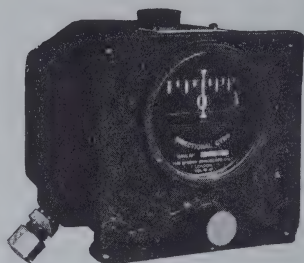
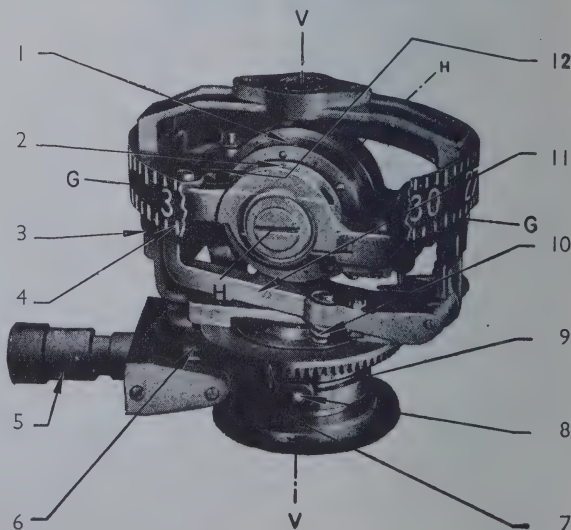


Fig. 4. The directional gyro is a fixed indicator of direction for steering straight courses and making precise turns.

Accurate steering of an aeroplane requires a fixed reference such as a star, the sun, or objects on the ground with which the heading of the aeroplane may be compared. The Directional Gyro affords the only fixed reference within the cockpit upon which the pilot can rely when outside visibility is obscured.

The magnetic compass alone is insufficient for steering in blind flight, even on a straight course. The slightest tilt of the aeroplane tilts the compass card and the vertical component of the earth's magnetic field, acting on the needles, gives the card a swing, setting up an oscillation which does not disappear until after the aeroplane has resumed a straight course. The pilot, attempting to hold the compass reading, follows the swing of the card and

Fig. 5. Mechanism of the Directional Gyro with casing removed and card-band cut away to show details of rotor and synchronising gear.



the aeroplane starts to turn, causing the swing to increase. The result is apt to be a spinning compass and an aeroplane out of control.

The magnetic compass, in spite of its limitations, must be retained as the only direction-seeking instrument within the aeroplane, but it can be relied upon only at such time as the Directional Gyro

shows that the aeroplane is flying on a straight course. The Directional Gyro remains fixed without swinging or oscillating, enabling the pilot to steer accurately on any given heading.

The following fault finding table is supplied by Messrs. The Sperry Gyroscope Co.:

TROUBLES	CAUSES	REMEDIES
Dial spins continuously in one direction or drifts excessively in either direction.	1. Excessive vibration. 2. Incorrect vacuum. 3. Air filter disc dirty, reducing air flow.	1. Check instrument board with vibrometer, and if vibration is more than .004in. apply shock absorbers. 2. Check vacuum in accordance with installation instructions. 3. Examine filter disc at bottom of instrument and replace if necessary.

INSTRUCTIONS

To renew filter disc (Directional Gyro). Lift out the snap ring that retains the filter disc at the bottom of the case with a scriber. Replace the filter disc with a new one. This type *cannot* be cleaned.

The shafts, pivots and ball bearings of the instru-

ment are lubricated before assembly in the case, and ordinarily no further lubrication will be required. It should be borne in mind, however, that continuous use of the instrument in hot climates results in the evaporation of oil, and replenishment becomes necessary.

THE SPERRY-HORIZON

AN aeroplane pilot has three "senses" which are affected by the position of his aeroplane in relation to the horizontal: (1) his eyes, which use the natural horizon or some other reference to keep the aeroplane in normal flight; (2) his inner ear which is really a minute form of spirit level; and (3) his "deep muscle sense," or the feel of his own weight.

It has been found that if poor visibility prevents the use of the eyes to keep the aeroplane in normal flight, the deep muscle sense and the inner ear cannot cope with the problem of defining the horizontal. This is due to several causes, the most important being that these senses naturally indicate the pull of gravity and cannot distinguish between that pull and the pull of other forces which act on them, such as centrifugal force or acceleration caused by change of direction or speed.

Unless he can use his sense of vision to determine his attitude with respect to the horizon, the pilot's sense of balance is confused and his special orientation is inaccurate. Even birds when blindfolded and released, are unable to continue flying normally, but will flutter to the ground in a manner entirely foreign to natural flight.

As the natural horizon is the reference which a pilot instinctively uses, the Sperry-Horizon (Fig. 6) was designed for use as a substitute when the natural horizon is obscured. It responds instantly, requires no interpretation, and provides a guide upon which the pilot may instinctively and naturally depend.

The artificial horizon may be thought of and used in either of two ways. Some like to consider it as a window through the instrument panel and through the fog or clouds, in which case the horizon bar (Figs. 6 and 7) is where the natural horizon would be. Others fly the miniature aeroplane with respect to the horizon bar.

The Sperry Horizon, Fig. 7, is operated by vacuum supplied by means of a venturi tube or by an engine-driven vacuum pump. The gyro, or rotor, is mounted in the case (1) and spins at approximately 10,000 r.p.m. about a vertical axis in the direction shown by the arrow. An indication from the gyro is picked up and brought around to the face of the instrument by a horizon bar (2) which is actuated by a pin (3) protruding from the case through a slot in the gimbal ring (4).

To keep the gyro upright, four pendulous vanes (one of which is shown at A, Fig. 7) are suspended from the under side of the gyro housing. Each one of these vanes partially covers one of the four air ports (B) that exhaust air from the gyro compartment. If the gyro departs from its upright position, gravity holds the vanes vertical, and one vane closes one port while the opposite vane opens its port as shown in Fig. 8. The reaction of the air emitted from this port moves the gyro, in the direction of C, which is at right angles to the air force. The rate at which the gyro precesses in response to the action of the pendulous vanes is so slow that the precessional forces created by the swinging of the vanes in rough air cancel one another before

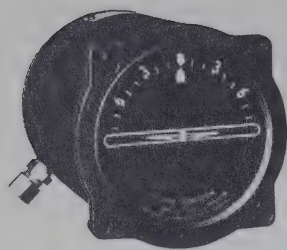


Fig. 6. The Sperry-Horizon, a direct reading indicator of flight altitude for bank, climb or glide.

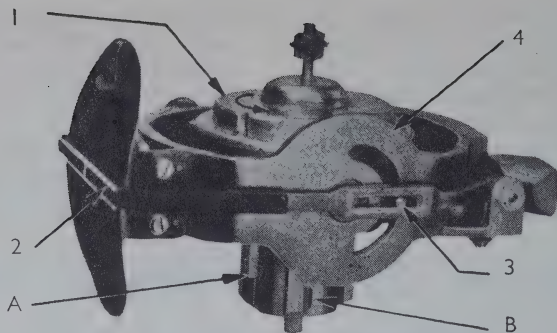


Fig. 7. Showing the principal parts of the Sperry Horizon. 1 is the case, 2 the Horizon Bar, 3 the Guide Pin, 4 the Gimbal Ring. A is a pendulous vane and B an exhaust port.

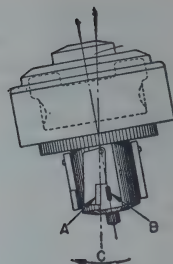


Fig. 8. A diagram which shows the principle of the erecting action of the pendulous vanes (see A in fig. 7).

they have time to displace the gyro.

The Artificial-Horizon is used as the basic reference for lateral and longitudinal control of the aeroplane. The horizon bar in the instrument remains parallel to the natural horizon while the miniature aeroplane is fixed to the case and remains parallel to the athwartships axis of the aeroplane. Lateral control is, therefore, accomplished by flying the aeroplane so as to keep the miniature aeroplane parallel to the horizon bar. For longitudinal control the horizon bar is connected to the

gyro in such a manner as to cause the bar to take a position relative to the miniature aeroplane equivalent to the position of the aircraft to the natural horizon. In other words, the miniature aeroplane is above the horizon bar when the aircraft is nose high and below the bar when the aeroplane is nose down. Thus longitudinal control is similar to lateral control in that control is applied to keep the miniature aeroplane on the horizon bar in the same manner that the nose of the aircraft is held on the natural horizon.

The following fault finding table is supplied by Messrs. The Sperry Gyroscope Co. :

TROUBLES	CAUSES	REMEDIES
Bar fails to respond.	1. No vacuum. 2. Air filter disc dirty, reducing air flow. 3. Leaks in instrument case.	1. Examine source of vacuum supply and tubing for leaks, stoppages or pump failure. 2. Examine filter disc at rear of instrument and replace if necessary. 3. See that all screws in instrument case are in place and tight.
Bar does not settle level.	1. Excessive vibration. 2. Low vacuum. 3. Air filter disc dirty, reducing air flow.	1. Check instrument board with vibrometer and if vibration is more than .004in. apply shock absorbers. 2. Check vacuum in accordance with installation instructions. 3. Examine filter disc at rear of instrument and replace if necessary.
Bar oscillates or shimmies.	1. Excessive vibration. 2. Vacuum too high.	1. Check instrument board with vibrometer and if vibration is more than .004in. apply shock absorbers. 2. Check vacuum in accordance with installation instructions.

The same notes on air filters and lubrication are appended as in the case of the Directional Gyro.

Photographs by courtesy of The Sperry Gyroscope Co., Ltd.

THE GYROPILOT

THE Gyropilot is not a new invention. In 1914 a Sperry Automatic Pilot (stabilizer) won the Grand Prize in Paris for safety in flight. It was not until the introduction of long range passenger services in the last few years prior to the war that the transport business was sufficiently stimulated to demand renewed activity in the design of automatic aeroplane control.

The Sperry Company had already developed an instrument combination for blind flying, the Directional Gyro and the Artificial Horizon. These instruments proved of such service in bad weather flying that they were incorporated in the new Gyropilot, being modified only as required to convert their indications of flight attitude into corrective movements of the aircraft controls. Dials similar to the dials of the separate instruments are contained in the Gyropilot control units and mounted on the instrument board, so that the human pilots are provided with a continuous indication of the course and altitude of the aircraft whether it is being flown by automatic or manual control.

HOW THE GYROPILOT OPERATES

THE aircraft is controlled by the Gyropilot about all three axes of angular motion—lateral, longitudinal and directional. It is flexible in operation, permitting manoeuvres under Gyropilot control to be made at the will of the human pilot.

Its action, based on pneumatic and hydraulic principles, ensures smooth, positive operation of the control surfaces of the aircraft. Having no clutches, motors or electrical contacts it is practically foolproof.

The instrument may be likened to the human body, but it detects smaller departures and acts on

The Gyropilot's most obvious advantage is that it relieves pilot and co-pilot of the physical burden of flying, so that their attention can be devoted to navigation, observation and radio-communication. Even in clear weather the Gyropilot is a boon because, with the trend towards higher altitude flying and larger aeroplanes, the fatigue of manual flying is much increased. The Gyropilot is particularly useful under blind flying conditions as it prevents the fatigue common to long periods of manual control.

Moreover, the navigation of aircraft by celestial sights, a very important consideration on long, over-water flights, is facilitated with the use of the Gyropilot, the pilots being free to concentrate on obtaining accurate sights.

The Gyropilot has introduced a new technique in aerial navigation. Whereas formerly it was almost impossible to steer much closer than two degrees by manual flying, the Gyropilot holds the aircraft steady to within half a degree off course. Besides improving the accuracy of navigation the Gyropilot saves time and fuel en route.

the controls with less delay through its "Brain," "Nerve" and "Muscular" systems than does the human body.

The control gyros are like the "Brain"—The servo unit the "Muscle," and the air relays and oil valves are like "The Nerve System" that ties the "Brain" and "Muscle" together in order to obtain action and control. The follow up system is also part of the "Nerve" system, carrying information back to the "Brain" from the "Muscle." The action of the Follow Up is such that control is applied in proportion to disturbance.

THE DIRECTIONAL GYRO

THE Directional Gyro is a free gyroscope, *i.e.*, free to move about three axes. A compass card is attached to it. The human pilot can engage the Directional Gyro with a caging knob and set it to the same course as the magnetic compass. The Directional Gyro must be compared periodically with the magnetic compass and reset if necessary.

Since the gyro with its compass card remains fixed in azimuth (except for wander, which should not average more than three degrees in fifteen minutes time) and neither swings nor oscillates like a magnetic compass, the instrument provides a dead beat steering indicator and directional control reference. The Directional Gyro forms one part of the "Brain" of the Gyropilot.

THE BANK AND CLIMB GYRO

THE Bank and Climb Gyro rotates with its axle vertical, as shown in Fig. 1, Y-Yi. This gyro must absolutely maintain its position. Four pendulous vanes (one of which is shown at "A" in Fig. 8 of last month's article) are added to the underside of the gyro housing. Normally each one of these vanes covers one of the four air ports "B" that exhaust air from the gyro compartment, as shown. When the gyro diverges from its upright position, as shown at the right, gravity holds the vanes vertical and one vane closes one port and the opposite vane completely opens its port. The force of air coming from this open port will move the gyro in the direction "C" back to its normal position.

The corrective movement C, at right angles to the air force, is called "Precession" a characteristic of all gyroscopes. The rate at which the gyroscope precesses in response to the action of the pendulous vane is so slow that the precessional forces created by the swinging of the vanes in rough air cancel one another before they have time to displace the gyro. Thus the Bank and Climb Gyro establishes a reliable and stable vertical which can safely be used as a reference for longitudinal and lateral control. In figure 1, the gyro maintains its position and therefore indicates the movement of the aircraft in a glide. In Fig. 2 the gyro indicates in degrees the movement in a bank.

The miniature aeroplane of the Bank and Climb Gyro is made to simulate the aircraft. The dial indicates the bank in degrees and the bar stimulates the natural horizon. The Bank and Climb gyro is the second of the two main units that form the "Brain" of the Gyropilot.

The changes in altitude which are visually indicated to the human pilot on the dials of the Gyropilot cause the controls for automatic flying to be actuated by a system of air pick-offs. The air pick-offs form the first stage of the "Nerve" system.

Around the gyros are the air pick-offs X-Xi as shown in Fig. 3. (There are three sets of air pick-offs, two connected with the Bank and Climb Gyro for lateral and longitudinal control and one with the Directional Gyro for directional control). To illustrate the action of the gyropilot only the aileron control will be used. (The rudder and elevator controls are operated in a similar manner). In actual practice the air pick-off consists of a disc

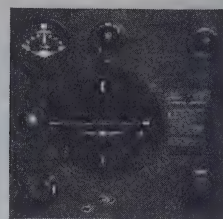
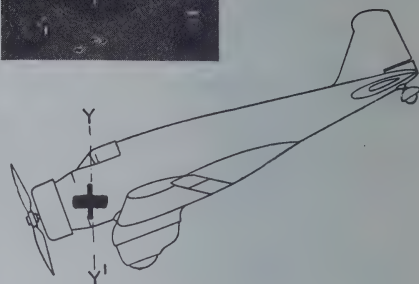


Fig. 1. As the aircraft drops its nose the gyro, maintaining its position, causes the miniature aeroplane to drop below the horizon bar, indicating a glide.



attached to the gyro element, with knife edges which intercept the air flow at two nozzles on the supporting frame. In the air pick-off (X-Xi) are two air ports (D-Di). In a neutral position air from the air relays (to be explained later) flows equally through the ports but when the aircraft deviates from level flight laterally as is happening in Fig. 3, the air pick-offs which form an integral part of the aircraft, take up the position as shown. Port Di is shut off and Port D is opened. Air therefore, flows through port D and actuates the air relay-operated oil valve, which transmits oil to the servo piston to move the ailerons in the correct direction to bring the aircraft horizontal. The operation is reversed if the aircraft takes the opposite direction.

As indicated gyro aileron pick-offs are placed in a box. Air is drawn into the bottom of the box by the suction pump M, and directed to the gyro to spin it. Air is also drawn in from the air relay (through ports D and Di when the aircraft is level) by the suction pump, and exhausted at the top. With the aircraft in the position as shown in Fig. 3, the box is tilted and air is drawn through port D only, as shown in Fig. 3, port Di being closed.

The "Nerve" system consisting of the air relay B and the balanced oil valve G, is shown lower down E is the diaphragm and F and K are two inlet ports smaller than the exhaust pipes to the air pick-offs

G is the balanced oil valve, which is connected to the air relay by the piston rod W. When the

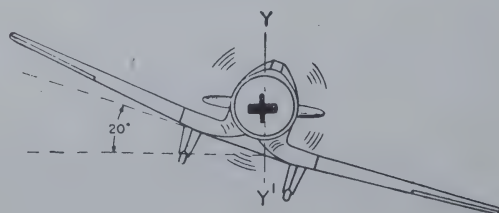
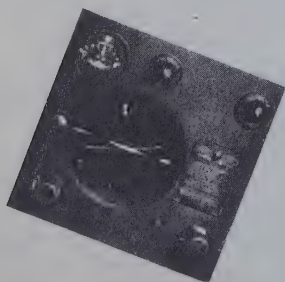


Fig. 2. Looking at the aeroplane from the rear: although the aircraft is banking the gyro continues to rotate vertically and the angle of the bank is indicated on the dial.

aircraft is level the system is neutral. Air is drawn through equally from the exhaust ports and entering through ports F and K, maintaining equal suction on both sides of the diaphragm. Therefore, there is no deflection of the diaphragm E, the oil valve piston remains in such a position that no oil is permitted to flow to the servo cylinder.

If the aircraft changes attitude laterally, one of the ports (D-Di) of the air pick-offs is opened fully and the other closed. This causes one side of the diaphragm in the air relay to receive increased suction while the suction on the other side falls off. Fig. 3 shows the operation of the nerve system when there is suction at D. The action of the diaphragm E moves the balanced oil valve to the right, permitting oil to flow to the servo unit through the pipe 2. Oil from the other side of the piston returns through pipe 3 and flows back to the sump through the pipe 4.

The "Muscular" system consists of three hydraulic servo cylinders, one of which is shown at the foot of Fig. 3. Oil enters one end of the cylinder and moves the piston, an equal amount of oil being exhausted from the other side of the piston and returned to the

sump. The piston rod (V-Vi) is connected to one set of the control cables of the aircraft.

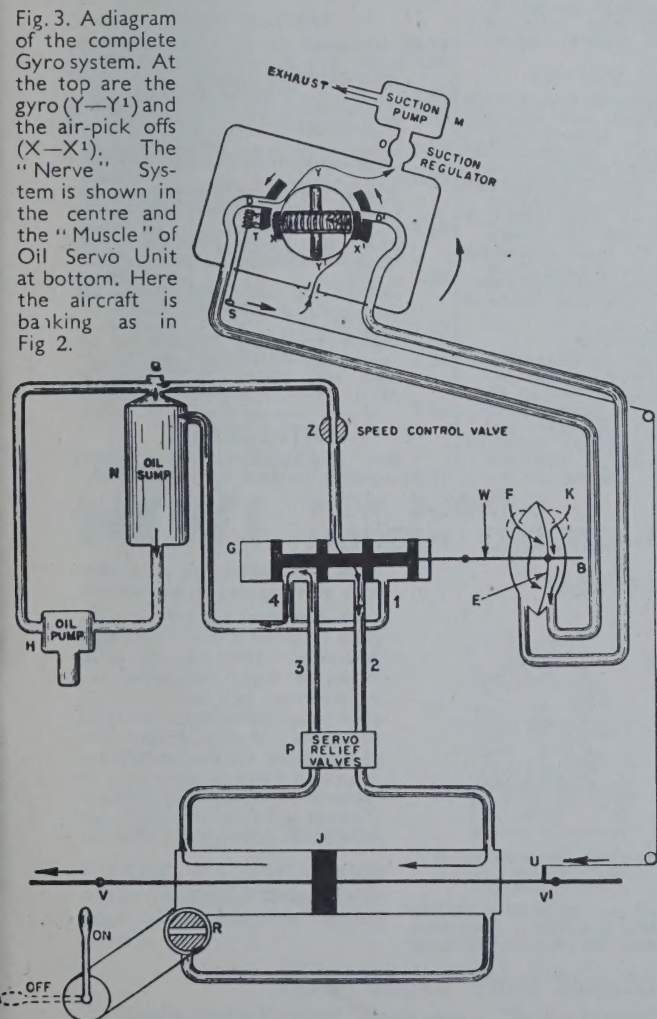
When the human pilot is flying the aeroplane manually, the valve R, Fig. 3, is opened, oil flows through the by-pass tube, and the controls can be moved freely.

Other components of the complete system as shown in Fig. 3 are as follows. O is a suction regulator which keeps the vacuum at 4in. Hg. regardless of the speed of the suction pump, which varies with the speed of the engine. The oil sump, N, carries the reserve oil. Q is a valve which regulates the oil pressure from the sump and permits it to circulate through the sump whenever the balanced oil valve cuts off circulation to the servo unit. The servo relief valves, one of which is shown at P, regulates the speed of oil flow to the servo pistons, and therefore controls the speed with which the Gyropilot operates the controls.

We must here mention the part of the "Nerve," system which constitutes the follow-up system. It must be remembered in controlling an aeroplane that it is not only necessary to apply control to bring the aeroplane back to level when it has been disturbed but also to begin to remove the applied control as the aeroplane is returning to level so that the control surface will be back in neutral when the disturbance has been fully corrected. A further requirement is that the amount of control applied be proportional to the displacement of the aeroplane. All this is necessary to both automatic and manual control and in the former is handled by the follow-up. The air pick-offs X-Xi are not fixed rigidly to the gyrobox and the plane, but instead can be moved in relation to them by the follow-up mechanism. A cable is connected to the servo piston rod at U and runs to the follow-up pulley S on the gyrobox. The pulley controls a gear T which is connected to a gear on the air pick-offs X-Xi which are commonly connected. When the piston V-Vi moves to the left, the follow-up cable at U moves likewise and gear T through the action of pulley S, moves X down and Xi up. When they reach a neutral position (both half open) the air relay and oil valve are centred and servo piston movement away from neutral is stopped. Now consider the control surface movement which the servo has been producing has been bringing the aircraft back to level flight. As the aeroplane continues to approach the true level the air pick-offs, which have driven ahead of the gyro box, pass beyond the neutral point and begin to cause servo movement in the opposite direction. This is not opposite control but is the removal of the control originally applied.

HOW THE GYRO PILOT IS USED

As soon as the aircraft is clear of the airport and on its course, the human pilot rotates the adjusting knobs on the Gyropilot control unit so that the three follow-up indicators match the



gyro indications for direction, bank and climb. Then he moves the engaging lever "on" and takes his hands and feet from the controls. The climb knob is adjusted to obtain the desired rate of climb. Once this is set, the aircraft continues climbing steadily until the cruising altitude is reached, at which time another slight turn of the climb knob puts the aeroplane in level flight.

For large turns the desired angle of bank is set in, and the turn knob rotated so as to turn the aircraft at the desired rate. If a small course change is required, it is only necessary to rotate the turn knob slowly to the right or left. When flying in co-operation with the radio beam the precision with which these small changes in heading can be made while the Gyropilot is in operation is an important factor in keeping the aeroplane on course.

On long flights a glide is often started as much as one hundred miles from the airport. A slight turn of the knob for glide is all that is necessary to obtain the desired gliding angle, and the Gyropilot thereafter maintains a steady rate of descent until the human pilot is ready to take over the controls, and make his landing.

To disengage the Gyropilot, the human pilot takes over the controls and moves the engaging lever "off." If necessary he can overpower the Gyropilot while it is in operation.

For the above data, descriptive matter and photographs I am indebted to Messrs. The Sperry Gyroscope Co. Thanks are also due to Mr. J. S. Pole of the Sperry Co. for checking over the script.

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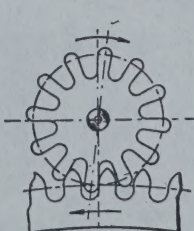


FIG. 25. Portion of a wheel meshing with a twelve-leaved pinion. Correctly depthed

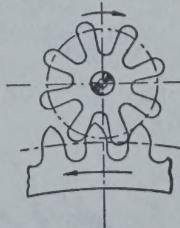


FIG. 26.—Eight-leaved pinion of correct size, but shallowly depthed

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